

Dr/Hany Abdou

From Waveform Interpretation to
Clinical Responsibility. [Evidence,
Ethics, and Real-World Practice]

Auditory Evoked Potentials in Clinical Decision- Making

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Potentials in Clinical
Decision-Making

Hany
Abdou

Auditory Evoked Potentials in Clinical Decision-Making

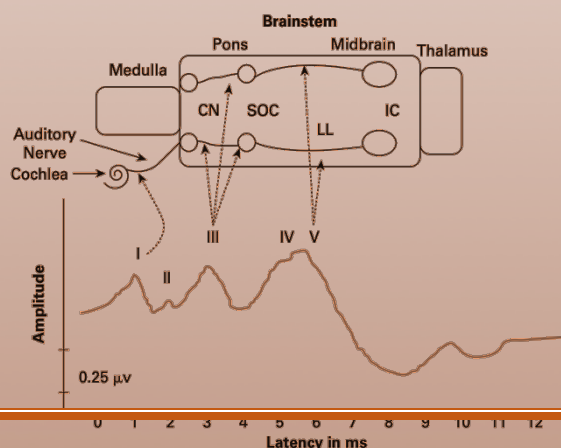
*{From Waveform Interpretation to
Clinical Responsibility}.*

*Evidence, Ethics,
and Real-World Practice*



Dr. Hany Abdou

M.Sc. Audio-Vestibular Medicine





قُلْ أَطِيعُوا اللَّهَ
وَأَطِيعُوا الرَّسُولَ
وَأَطِيعُوا أَرْوَاقَكُمْ



The Moment Before the Decision



*The room is **quiet**.*

*The screen is **bright**.*

Waveforms are perfectly formed, clean, reproducible, — and reassuring.

The report template is already open.

The cursor blinks under a familiar sentence,

“Results are within normal limits.”

The parent is waiting outside.

Nothing on the screen looks alarming.

Yet something does not feel right.

*The **history** does not fit.*

The concern in the parent’s voice still echoes.

*The child’s development does not align with the comfort promised by the word **“normal.”***

The machine has finished its job.

Now the responsibility shifts.

No guideline will step in.

No protocol will make the decision.

No waveform will explain what to say next.

This is the moment no textbook prepares you for.

Not the moment of recording,

but the moment of interpretation.

Not the science,

but the consequence.

***—This book begins here,
at the exact point where evidence ends,
ethics begin,
and real life refuses simple answers.***





Why This Book Is Different



This book was not written to replace the classics.

It was written because living with patients revealed what the classics could not fully cover.

For decades, the field of auditory evoked responses has been shaped by foundational works that defined physiology, methodology, and signal interpretation.

These books remain essential

They taught generations how to recognize waves, measure latencies, and understand neural generators.

But clinical reality has evolved.

Patients today are not textbook cases.

Clinical decisions today are not academic exercises.

And evoked responses today are no longer used only to describe physiology, but to justify actions.

This is where the gap begins.

What the Classics Gave Us

Katz organized the science.

Hall structured the physiology and methodology.

Linda Hood clarified applications and patterns.

Together, they built the intellectual foundation of auditory evoked testing.

They answered questions such as:

- *What is this response*
- *Where does it come from*
- *How is it measured*
- *How does pathology alter it*

These contributions are irreplaceable.

This book stands on their shoulders.

A map of authority

Includes:

- *Hall*
- *Hood*
- *Katz*
- *AAA / ASHA / BSA / JCIH*

But framed as:

“What we learned from them... and where clinical reality forced evolution.”

This book is written from the examination room, the report desk, and the moment before a decision is signed.

Clinical reality introduced questions such as:

- *When is a technically perfect result clinically wrong*
- *When does reassurance cause harm*
- *When should uncertainty be documented instead of resolved*

- *Who carries responsibility when decisions are based on evoked data*

These questions are not theoretical.

They are lived daily in clinics, hospitals, and medico-legal settings.

From Interpretation to Responsibility

*Traditional texts focus on **interpretation**.*

*This book focuses on **responsibility**.*

It does not ask only:

- *What does this waveform mean*

It also asks:

- *What decision will this interpretation trigger*
- *Who will be affected by this report*
- *What cannot be promised based on this result*
- *What must be written to protect the patient and the clinician*

Evoked responses are no longer neutral measurements.

They have consequences.

From Normal and Abnormal to Gray Zones

*Classic teaching often divides results into “normal” and
“abnormal.”*

Clinical reality is rarely that clean.

This book addresses:

- *borderline findings*
- *gray-zone responses*
- *technically acceptable but clinically misleading results*
- *situations where physiology and behavior disagree*

*Not to create confusion,
but to teach safe decision-making inside uncertainty.*

From Tests to Decisions

*This book is not organized around **tests**.*

*It is organized around **decisions**.*

It asks:

- ***Why are we testing***
- ***What question are we trying to answer***
- ***What decision will follow***

*Evoked responses here are treated as decision support tools, not
decision makers.*



What This Book Adds

This book adds:

- *A decision-based framework*
- *Ethical boundaries for interpretation*
- *Medico-legal awareness in report writing*
- *Real-world case logic*
- *Language that reflects uncertainty without weakness*

It does not compete with the classics.

It completes the conversation they began.

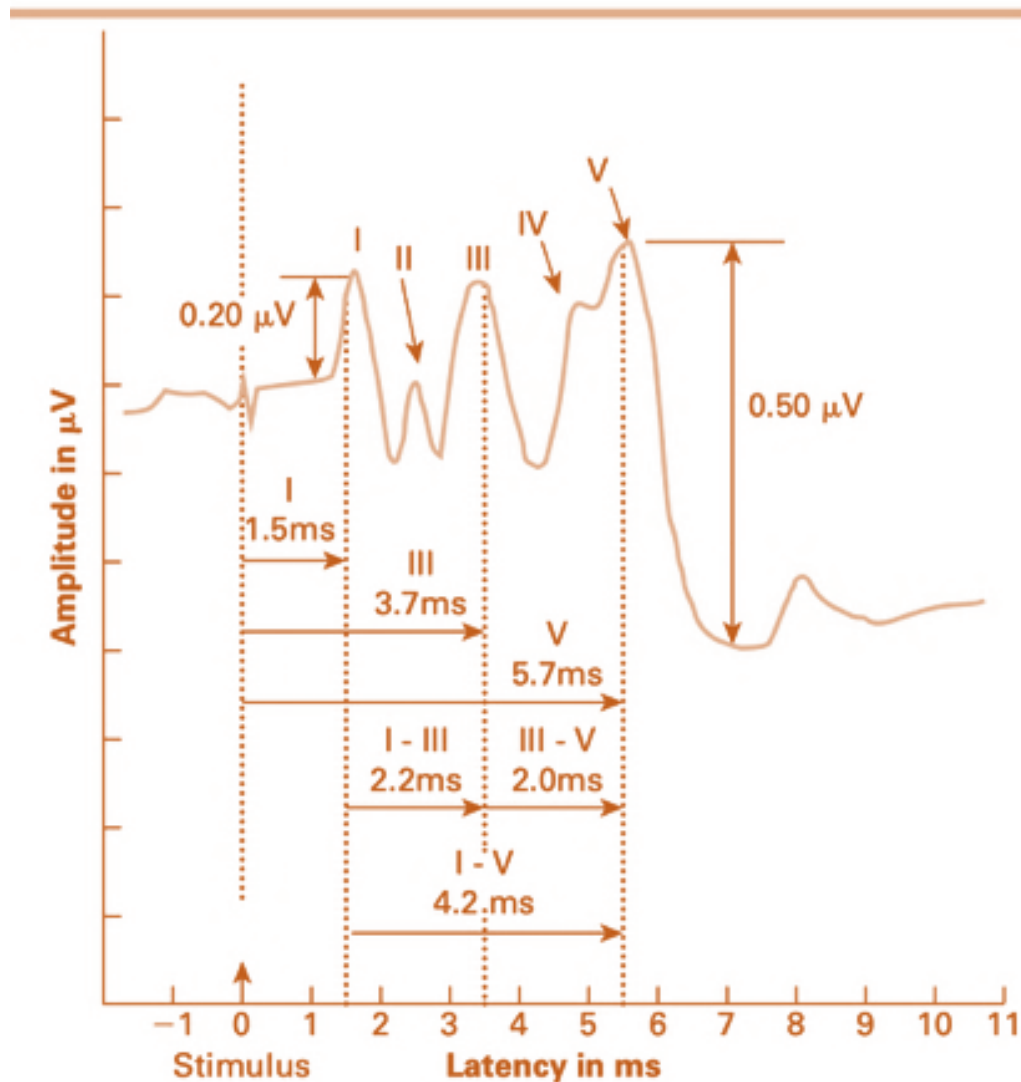
Who This Book Is For

This book is written for clinicians who:

- *already know the waves*
- *already understand the protocols*
- *but now carry responsibility for outcomes*

It is for those who have learned that the hardest part of evoked testing is not recording the response, but standing behind the decision it informs.





Machines record.

Manufacturers design.

But only clinicians are accountable.

This book begins where physiology ends.

Dr. Hany Abdou

M.Sc. Audio-Vestibular Medicine





Preface



*This **book** was written because audiology needed a different kind of reference.*

Not another book that explains tests.

Not another book filled with waveforms, latencies, and definitions.

*But a book that explains **responsibility**.*

For decades, legendary authors shaped our understanding of auditory evoked responses.

James Hall laid the scientific foundations.

Linda Hood refined clinical interpretation.

Their work remains essential.

And this book proudly stands on their shoulders.

But modern audiology faces a different challenge.

Today, the problem is rarely how to record a response.

*The problem is what happens **after** the response appears on the screen.*

The interpretation.

The report.

The decision.

And the consequences that follow.

In real clinical practice, especially in pediatric and objective assessment,

a single sentence in an audiology report can:

- *trigger intervention*
- *delay management*
- *change a rehabilitation pathway*
- *or shape a family's expectations for years*

This book was written for that moment.

This is a book about thinking under responsibility.





What This Book Is — and What It Is Not



This is not an encyclopedic textbook.

It does not aim to replace classic references.

Instead, it focuses on something often underemphasized:

clinical thinking between the test and the decision.

Here, evoked responses and ABR are not treated as technical procedures,

*but as **decision-support tools** that carry ethical, clinical, and medico-legal weight.*

A Different Way of Learning

Each chapter in this book follows a consistent structure designed for real clinical use.

*Beyond explanation, every chapter ends with a structured **End of Chapter – Clinical Summary**, referred to throughout this book as the **Clinical Responsibility Framework**.*

This framework goes far beyond traditional summaries.

It includes:

- ***Key Points***
- ***Golden Rules***
- ***Common Mistakes***
- ***Red Flags***

- *Pitfalls*
- *Evidence-Based and International Best-Practice Principles*
- *Clinical Decision-Making guidance*
- *clinical scenarios*
- *Thinking behind the scene*
- *Ethical considerations*
- *Documentation and report writing*
- *Medico-legal pitfalls*
- *A final clinical message*
- *Clear take-home messages*

All these for

safe decision-making under pressure.



Why This Matters

Evoked responses often speak for patients who cannot speak for themselves.

Infants.

Young children.

Patients who cannot cooperate.

Decisions made at this stage are rarely reversible.

This book respects that responsibility.



Who This Book Is For

This book is written for:

- *Audiology students and interns*
- *Early-career clinicians*
- *Practicing audiologists involved in objective testing*
- *Professionals working closely with ENT and multidisciplinary teams*

The language is intentionally simple, clear, and global.

No unnecessary complexity.

No academic intimidation.

Only what serves patient care.

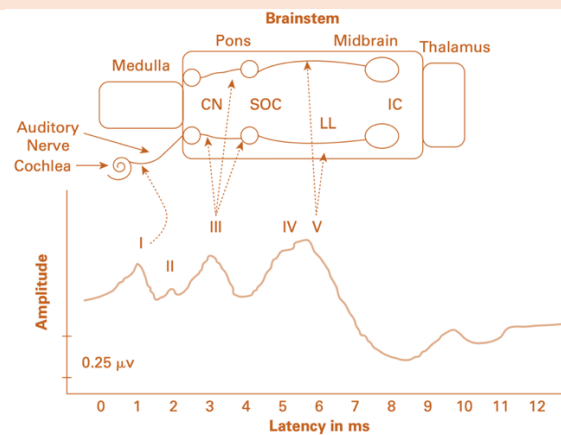


A Final Word Before You Begin

*Evoked responses are **powerful**.*

*ABR is **powerful**.*

But power without judgment is dangerous.



As you turn the page, remember:

The waveform is recorded by the system.

The decision belongs to you.

Dr. Hany Abdou
M.Sc. Audio-Vestibular Medicine

About the Author



Dr. Hany Abdou is an **audiology physician** specializing in **audio-vestibular medicine**, with extensive clinical and academic experience in objective hearing assessment and **pediatric audiology**.

His work focuses on bridging the gap between **diagnostic testing and clinical decision-making**, particularly in high-impact areas such as **auditory evoked responses, ABR interpretation, and audiology report writing**.

Dr. Hany Abdou has spent years working in busy clinical environments where audiology decisions are made under real pressure—often for patients who cannot communicate, and where test results directly influence lifelong outcomes.

Alongside clinical practice, *Dr. Hany Abdou* is actively involved in teaching and mentoring audiology students and early-career clinicians.

He is the author of

The Art of Evidence-Based Best Practices in Audiology Report Writing

, a widely praised work known for its practical focus, clear language, and real-world applicability.

His writing style combines evidence-based principles with straightforward language and clinical storytelling, aiming to make complex concepts accessible without oversimplification.

This book reflects that philosophy.

Dr. Hany Abdou is an:

Audiology Physician, Abha Maternity & Pediatric Hospitals, Saudi Arabia.

&

Lecturer of Audiology, King Khalid University.

*With respect for science,
and responsibility toward patients,*

Dr. Hany Abdou
M.Sc. Audio-Vestibular Medicine





Acknowledgments



This book is not just my work—it is the result of countless people who stood beside me on this journey.

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*And finally, to all the students and interns, whose questions, curiosity,
and passion for learning pushed me to create something truly useful
for the next generation of audiologists—this book is for you.*

*May this guide be more than just a reference—may it be a companion
in your clinical practice, helping you master*

Auditory Evoked Potentials in Clinical Decision-Making

With gratitude respect and warm regards,

Dr. Hany Abdou

M.Sc. Audio-Vestibular Medicine





How to Use This Book



This book is designed to be used—not just read.

You do not need to read it from cover to cover in one sitting.

Instead, think of it as a clinical guide that grows with your experience.

Before You Begin

Start by reading the opening sections carefully.

They establish the clinical mindset that guides everything that follows.

Understanding how to think is more important than memorizing details.

How the Chapters Are Structured

Each chapter follows a consistent structure:

- *A clear clinical explanation of the topic*
- *Practical interpretation guidance*
- *Real-world context*
- *An **End of Chapter – Clinical Summary**, referred to as the **Clinical Responsibility Framework***

This framework is the heart of the book.

It is designed to help you:

- *review quickly*
- *identify risks*
- *avoid common errors*

- *make safer clinical decisions*

*In selected chapters, you will also find an additional **Layer** designed for moments of clinical pressure.*

How to Read as a Student or Trainee

If you are a student or early in your career:

- *Read chapters sequentially to build a strong foundation*
- *Focus on **Key Points** and **Golden Rules***
- *Use the **Common Mistakes** and **Red Flags** sections to protect yourself during training*
- *Revisit the **Take-Home Messages** before exams or clinical sessions*

This book is meant to reduce confusion—not add to it.

How to Use in Clinical Practice

If you are already practicing:

- *Use chapters as quick references before or after testing*
- *Review the **Clinical Decision-Making** and **Report Writing** sections regularly*
- *Use the **Medico-Legal Pitfalls** as a safety checklist*
- *Apply the **Final Clinical Message** as a mental checkpoint before signing reports*

The book is structured to support real-time clinical reasoning.

How to Use with Multidisciplinary Teams

Audiology does not work in isolation.

This book is written to support communication with:

- *ENT specialists*

- *pediatricians*
- *speech and language therapists*
- *rehabilitation teams*

Clear reasoning and cautious language help ensure your findings are understood and used correctly.

Using the Book Over Time

As your experience grows, the same content will reveal deeper layers of meaning—especially in sections related to ethics, documentation, and decision-making.

This book was not written from theory.

It was written from real clinics, real parents, real risks, and real consequences.

This is not a book about perfect recordings.

It is a book about safe decisions.

Privileges are not rewards.

They are risk-based permissions.





A Final Tip



*Do not rush to **conclusions**.*

*If a chapter leaves you **thinking** rather than certain, **it has done its job**.*

*Clinical confidence grows from **reflection, not speed**.*

*This book is not about **mastering tests**.*

*It is about mastering **responsibility**.*

In audiology, technology has advanced faster than thinking.

Screens look cleaner.

Waveforms look sharper.

But decisions have become heavier.

A single result can change a life.

This book was written to slow that moment down.

Not to delay action,

but to protect it.

*We believe that audiology **is not a technical profession**.*

*It is a **clinical one**.*

Tests do not make decisions.

Clinicians do.

*We believe that **cautious language** is a sign of professionalism,
not weakness.*

***Evoked responses are powerful tools,
but power without judgment is dangerous.***

We believe that every report is a clinical act.

Every sentence carries weight.

Every word can guide—or misguide—another professional.

Writing is part of diagnosis.

Documentation is part of ethics.

We believe that early decisions matter most.

Especially when patients cannot speak for themselves.

Infants.

Children.

They deserve clarity, not assumptions.

Guidelines guide.

Judgment decides.

This book stands on the shoulders of giants.

where time is limited, pressure is high, and mistakes are costly.

*Every chapter in this book ends with **responsibility**.*

*Read **carefully**.*

*Think **deeply**.*

*Decide **responsibly**.*

The waveform is recorded by the system.

The decision belongs to you.



*Before the chapters begin,
pause.*



Not to **rest**—

but to **reset**.

What follows is not a collection of tests.

It is a sequence of decisions.

You will see waveforms.

You will read numbers.

***But this book will ask you to look beyond them
every chapter ends with responsibility.***

Responsibility to the patient.

Responsibility to the family.

Responsibility to the profession.

And responsibility to yourself.





A Letter to the Young Audiologist



Dear Colleague,

*You entered this profession because you wanted to help people **hear, balance, and reconnect with their world.***

That intention matters. Hold on to it.

*Along the way, you will learn **tests, protocols, devices, and reports.***

*You will also learn something less obvious, that **good practice is not only about what you can do, but about what you should do, and when to ask for help.***

*Do not confuse **confidence with authority.***

*Do not confuse **experience with permission.***

*And never confuse **silence with agreement.***

***Respect your scope,** not because you are limited, but because **clarity** protects patients, colleagues, and yourself.*

Documentation is not paperwork.** It is **memory, accountability, and protection.

*You will work with **physicians, nurses, technicians, administrators, and industry.***

Collaboration is not weakness.

Ethics is not optional.

*If one day your work is questioned, let your records speak calmly on
your behalf.*

Let your policies stand with you.

And let your integrity remain untouched.

You do not need to know everything.

You need to know where you stand.

*Practice with **skill**.*

*Decide with **humility**.*

*Document with **honesty**.*

And remember,

professionalism is measured long after the test is finished.

With respect,

Dr. Hany Abdou





DISCLAIMER



*This book is intended as an **educational and professional reference** for Audiology and Audio-Vestibular Medicine practice.*

*The content reflects **international evidence-based principles**, published guidelines, consensus statements, and widely accepted best-practice frameworks. It is designed to support **clinical decision-making**.*

*This book **does not constitute**:*

- *Legal advice*
- *Regulatory directives*
- *Institutional policy mandates*
- *A substitute for national laws, local regulations, or hospital-approved policies*

All clinical actions, interpretations, and decisions must comply with:

- *Regulations of the **Saudi Ministry of Health (MOH)***
- *Requirements of the **Saudi Commission for Health Specialties (SCFHS)***
- *Institutional bylaws, credentialing processes, and approved clinical policies*

References to medical devices, software platforms, manufacturers, or commercial products are provided **solely for educational illustration**. Such references **do not constitute endorsement, recommendation, sponsorship, or preferential promotion** of any company, product, or service.

Scope of practice, credentialing, and clinical privileges vary between institutions and jurisdictions.

Any examples, templates, or policy models included are provided **for reference only** and must not be implemented without **formal institutional approval**.

The author assumes no responsibility for clinical decisions, patient outcomes, or professional actions resulting from the use or misuse of this content.

Ultimate responsibility for patient care rests with the licensed practitioner acting within approved scope and privileges.



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SECTION

1

Introduction to Auditory Evoked Responses



CHAPTER

1

Introduction to Auditory Evoked Responses

Figure 1.1. Dr. Hallowell Davis (1896-1992), Father of Auditory Evoked Responses.(Image courtesy of James W. Hall, III.).

Audiology begins with a simple truth:

sound enters the ear, but meaning is created in the nervous system.

Most of the time, we ask the patient what they hear.

Sometimes, the patient answers.

Sometimes, they cannot.

And yet, decisions must still be made.

This is where auditory evoked responses come in.

For decades, ongoing electrical activity in the brain has been detected as spontaneous potentials, commonly referred to as

Electroencephalography (EEG).

The first published recordings of EEG and evoked potentials in mammals were presented by a Russian scientist in 1912.

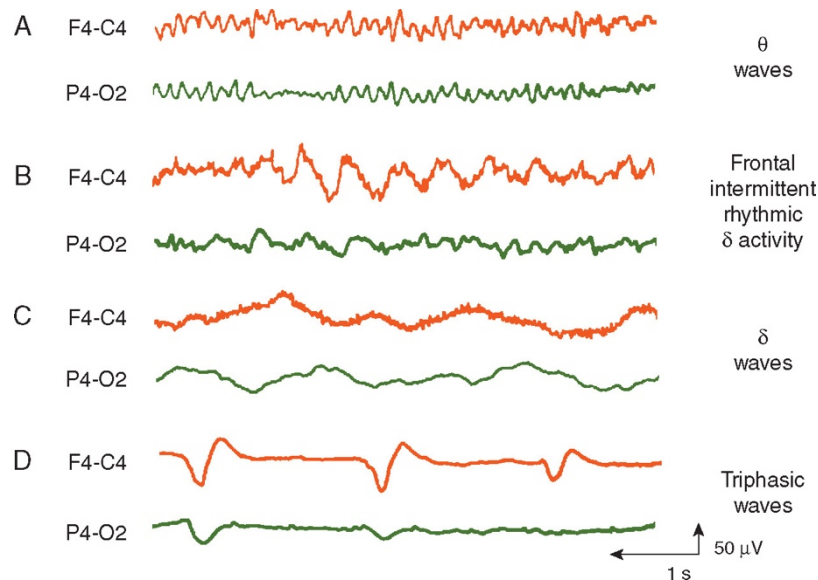


Figure 1.2. Neurodiagnostic tests, including the electroencephalogram (EEG)

Auditory evoked responses represent one of the most powerful objective tools in modern audiology.

They allow clinicians to assess auditory system integrity without requiring an active behavioral response.

This chapter establishes the conceptual and physiologic foundation necessary for understanding how evoked responses are generated, recorded, and applied clinically.

Before interpreting any evoked potential waveform, the clinician must understand:

- *What an auditory evoked response truly represents*
- *Where in the auditory system it is generated*
- *How neural synchrony and timing shape the recorded signal*

- *Why evoked responses are objective, yet not immune to clinical misinterpretation*

This chapter sets the framework for all subsequent chapters and clinical applications.

*Auditory evoked responses are **time-locked electrical signals** generated by neural structures within the auditory system following acoustic stimulation.*

These responses are recorded from surface electrodes and represent the summed activity of neural populations rather than single neurons.

Physiologic Basis

Evoked responses depend on three fundamental physiologic principles:

- **Neural activation** in response to sound
- **Synchronous firing** of neural populations
- **Temporal consistency** relative to stimulus onset

Without precise neural synchrony, evoked responses cannot be reliably recorded, even if cochlear function is preserved.

Time-Locked Neural Activity

A defining feature of auditory evoked responses is that neural activity occurs at a consistent time interval following stimulus onset. This allows:

- *Signal averaging to enhance response visibility*
- *Separation of stimulus-related activity from background EEG noise*
- *Objective confirmation of physiologic origin through replication*

Auditory Evoked Potentials (AEPs)

- Recording electrodes is very close to the source of AP **Near field** recording.
- If recording is done at a distance from the generating response & electrodes placed on scalp **Far field** response.

Classification of Auditory Evoked Potentials

- **Early response:** 1-10 msec.

Echoch G & ABR

- **Middle response** : >10-100 msec.

SN10 & middle latency response & early cortical

- **Late response:** >100-1000 msec.

Late cortical, P300 & mismatch negativity

ABR Latency 10 msec.

Amplitude: < 1 μ V

MLR Latency 100 msec.

Amplitude: < 10 μ V

Late Latency >100msec.

Amplitude: 10- 50 μ V

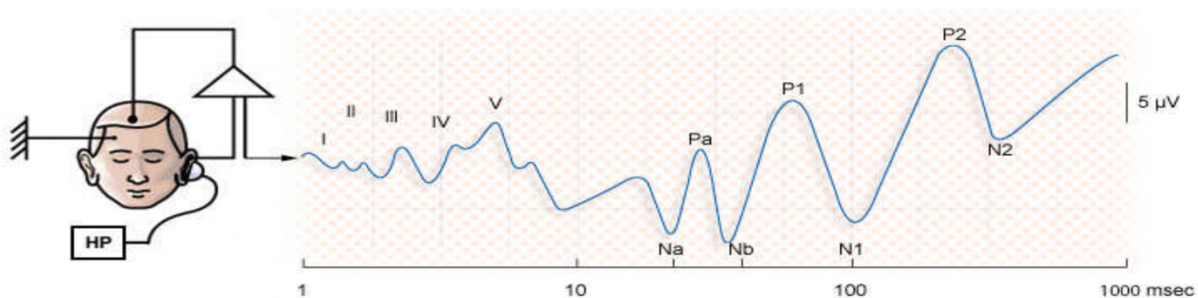


Figure 1.3. Classification of Auditory Evoked Potentials

What Are Auditory Evoked Responses?

Auditory evoked responses are **electrical signals generated by the auditory system** after sound stimulation.

ABR is an early potential, which occurs shortly after the onset of the stimulus.

- *ABR is a far-field recorded potential because the electrodes are placed on the scalp or on the ears, far from the potential generator.*
- *ABR is an exogenous potential because it is dependent on external factors.*

They are:

- *Objective*
- *Time-locked to the stimulus*
- *Recorded without requiring a behavioral response*

They reflect neural activity at different levels of the auditory pathway—from the cochlea to the cortex.

In simple terms:

they allow us to observe hearing without asking the patient to respond.

Auditory Brainstem Response

Waveform

- *The ABR consists of a series of seven positive-to- negative waves, occurring within 10 msec. following stimulus onset.*
- *Several systems of nomenclatures have been devised for labeling the individual wave form peaks.*
- *The most popular convention is to label positive peaks with Roman numerals (Jewett, 1970).*

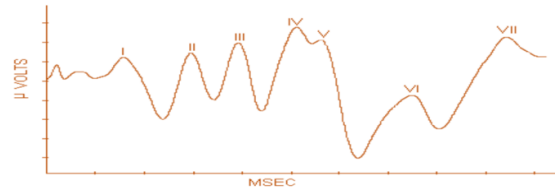


Figure 1.4. ABR waves: I- VII with positive polarity up.(Image courtesy of James W. Hall, III.).

Auditory brainstem Response Generators

- ***ABR reflects the neural activity in the auditory pathway from VIII nerve up the rostral brainstem***

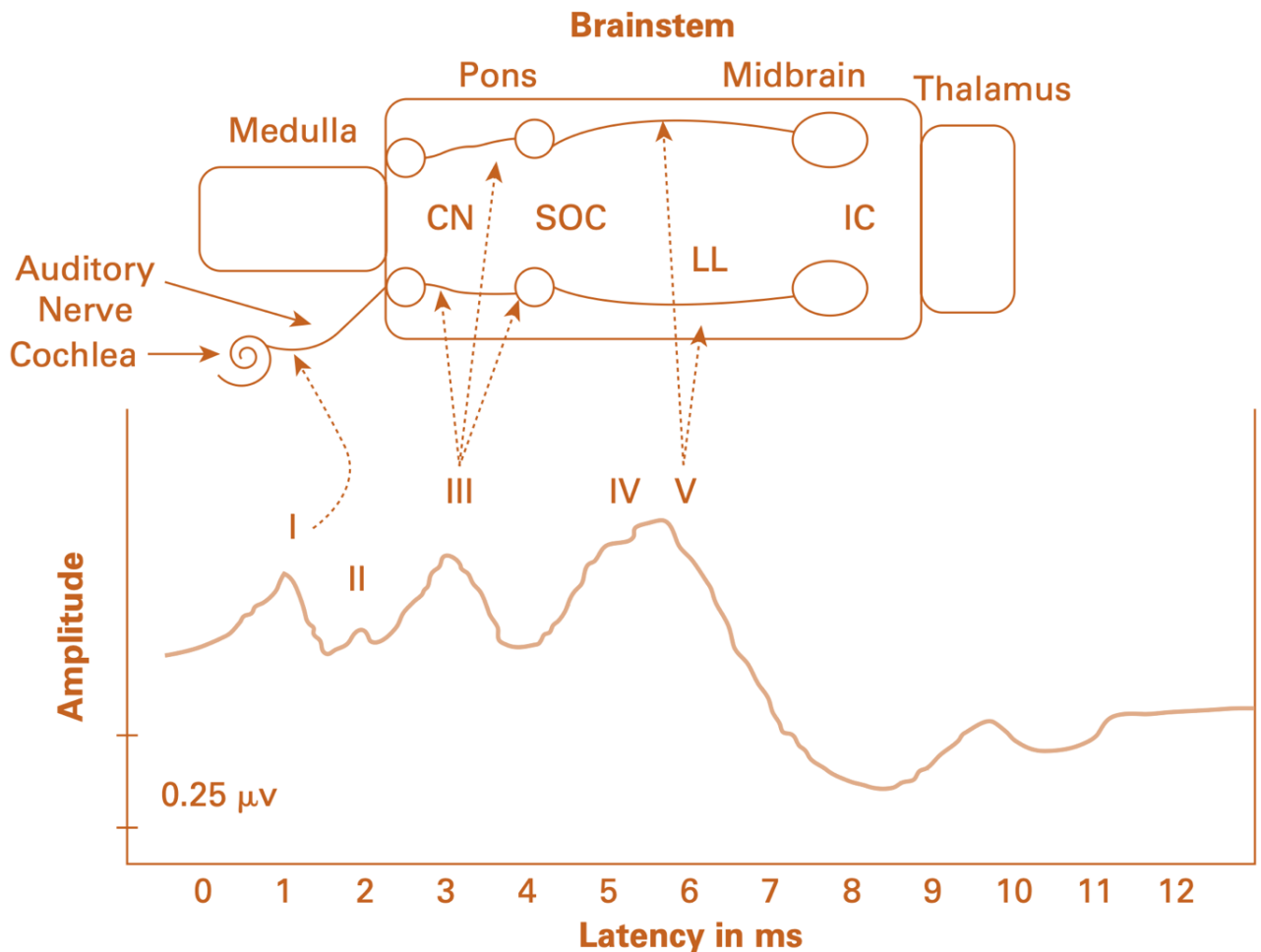


Figure 1.5. Anatomical generators of the auditory brain-stem response (ABR).The relation between ABR components and auditory structures is described in the text.Abbreviations are as follows:CN= cochlear nucleus SOC = superior olivary complex LL= lateral lemniscus IC= inferior colliculus.(Image courtesy of James W. Hall, III.)

ABR Recording

- ABR is generally low in amplitude & is easily buried in a background of relatively high amplitude ongoing EEG activity & other biological signals.

Improve S/N ratio

Several stages of processing

signal averaging

Differential recording, amplification & filtering

Artifact rejection

1- Signal Averaging

- Averaging is to enhance the time- locked responses to a stimulus relative to non time- locked background noise.
- Background noise is random & with repetition, its amplitude at any given instant will tend to average zero while the time locked response waveform will sum up over time.

2- Differential Recording

- ABR is recorded from electrodes attached to various positions on the head.

Non inverting electrode (+)

Inverting electrode(-)

Ground electrode

- ABR is recorded by measuring the differences in electrical activity between the two electrodes.
- Low and equal impedance at the electrode sites is mandatory to improve S/N ratio.

3- Amplification

- *Differential input preamplifier*
- *It selectively reject common mode signals*
(similar voltages at the two inputs are cancelled)
- *It passes a differential signal (voltages that are different at the two inputs are passed through & amplified)*

4- Filtering

- *ABR has greatest energy in the area of 900Hz*
primary energy of ABR at 900Hz

Band pass filters

150- 3000 Hz (Adults)

30-3000 Hz (Children)

ABR Recording & Stimulus Parameters

- *ABR is an onset response that is generated by the onset of an auditory stimulus.*
- *Stimulus onset must be rapid to synchronize all the neurons.*
- *Ideal stimulus Click with an instantaneous onset*
- *Response: good neural synchrony with clearly defined ABR*
- *However, click is not frequency specific*
- *Stimulus rate:-*
- *To eliminate non random noise , stimulus rate should not be an even multiple of the noise*

frequency such as 60 Hz hum

Stimulus rate: 11.1/sec

21.1/sec up to 71.1 /sec.

ABR Recording Overview

- *To record ABR , The following is required:*
- *1- generate an acoustic stimulus*
- *2- Amplify the very small electrical signals*
- *3- Numerically process the signal to obtain the averaged waveform*
- *4- Display or plot the averaged waveform*

Clinical Applications of ABR

1- Auditory threshold estimation

2- Otoneurological assessment

3- Newborn hearing screening

4- Diagnosis of ANSD

5- ABR in central auditory processing disorders

5-Intraoperative monitoring

Auditory Threshold Estimation

• *ABR is an important tool for the evaluation of auditory sensitivity in those individuals who are not readily testable by conventional behavioral audiometric procedures*

• ***Infants & children (Pediatric Population)***

• ***Multiply handicapped children & adults***

• ***Autistic subjects***

• ***Subjects suspected of pseudohypoacusis***

Auditory Threshold Estimation

• ***Clicks***

• ***Tone bursts***

• ***ABR :AC***

• ***ABR:BC***

Absent click ABR does not imply the absence of hearing but it suggests a severe to profound hearing loss within 1-4KHz.

- *A normal click ABR threshold does not necessarily imply normal hearing, Rather, it implies an area of normal sensitivity between 1-4 KHz.*

ABR click is not a direct measurement of hearing sensitivity.

Otoneurological Assessment

- ***ABR is sensitive to detect retro cochlear lesions***

Auditory nerve & Brainstem pathways.

Tumours

Demyelinating disease (MS)

Vascular insult

Head trauma

Abnormal ABR merely indicates the possibility of a retro cochlear lesion, not the type of lesion

Merits of ABR

- *ABR is highly stable & robust*
- *It can be recorded in :*

Coma

Under anaesthesia

- *It is insensitive to*

Alertness & tension

Sleep state

Medications

Drawbacks of ABR

- Click ABR cannot be used to assess sensitivity in specific frequency regions , but rather provide a gross estimate of hearing sensitivity.
- It is markedly affected by artifacts
- The ABR test can be completed only if the child is sleeping or lying perfectly still, relaxed and with eyes closed is affected
- Sedation is required in children and may need anaesthesia
- Test preparation & administration takes around one hour.

ABR is an important clinical tool for estimating hearing sensitivity and assessing the integrity of the auditory nerve & auditory brainstem pathways.

Basic ABR Response parameters

A- Absolute Latency

B- Inter-peak latency

C- Peak amplitude

D- Peak to peak amplitude

E- V/I amplitude ratio

F- Waveform morphology

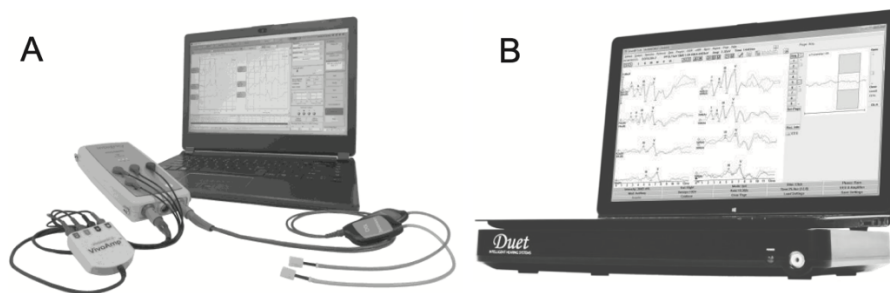


Figure 1.6. A AND B. Some examples of ABR units used to record neurodiagnostic and threshold ABRs. A. vivosonic Integrity 500. B. Intelligent hearing Sys- tems Duet. Source: Photos courtesy of vivosonic Inc. (A) and Intelligent hearing Systems (B).

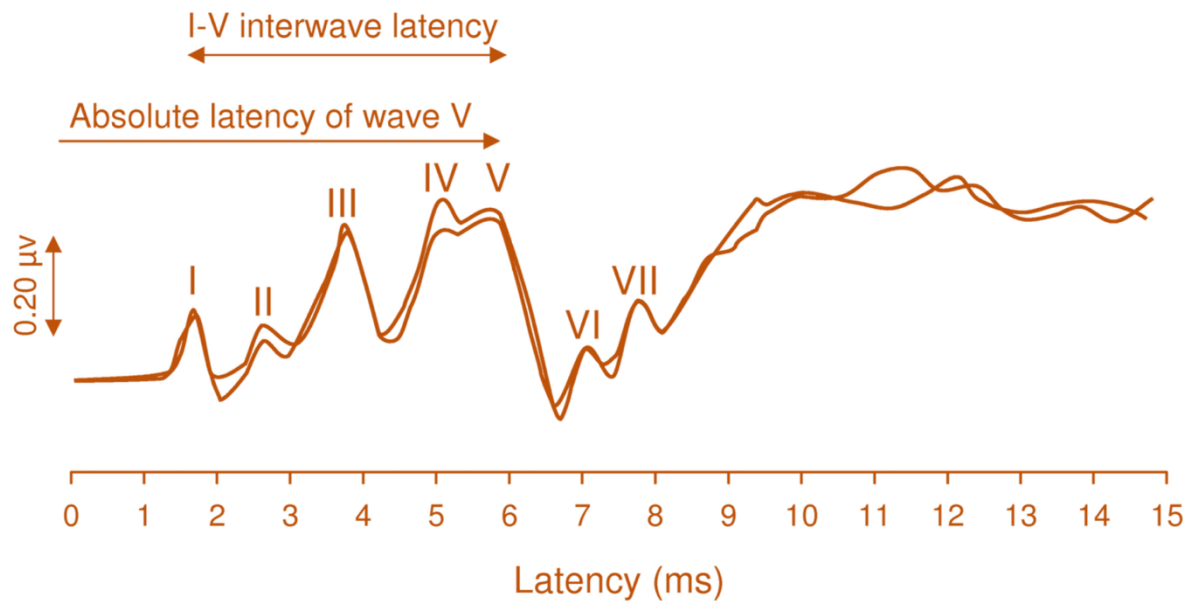


Figure 1.7. A normal auditory brainstem response (ABR) waveform to a click at a relatively high intensity level showing the waves (positive peaks) labeled I–VII.

The latency (time) of each wave is called the absolute latency, which is relative to the onset of the brief stimulus (at 0 ms). An example of absolute latency is shown for wave V, which is usually the most prominent wave. The latency difference between any two waves is called the interpeak latency difference. The I–V interpeak latency difference is the one most often used clinically. Waves II, IV, VI, and VII are often difficult to discern and are not used clinically. (Image courtesy of James W. Hall, III.).

A- Absolute latency

- The most widely and clinically applied measure because it is the robust one.
- It is the time elapsed in msec between the onset of acoustic stimulus and the waveform peak.
- The exact point on the waveform for calculating absolute latency is measured at a point representing the beginning of the down-slope of a given peak component.
- However peak latency may be difficult to determine accurately if the amount of residual noise in the average is too high.

Noise may add to the response peaks and alter their latencies.

Wave I occurs at about 1.6 msec, subsequent waves occur, approximately at 1 msec.

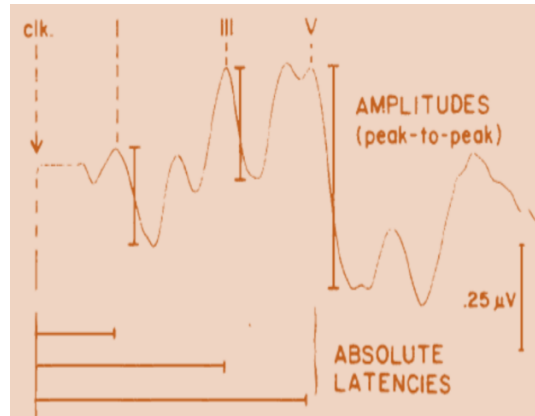


Figure 1.8. Absolute latency

B- Inter-peak Latency (IPL)

- It is the time difference between individual peaks of a given waveform and reflects the conduction time between neural structures

I – III IPL: Conduction time from lower auditory brainstem

III – V IPL: Conduction time from upper auditory brainstem

I – V IPL: overall index of auditory brainstem transmission

I – V IPL: 4 msec (Brainstem transmission time)

Inter aural peak difference of wave V does not exceed
inter aural peak difference of wave V does not exceed 0.3 msec.

C - Peak Amplitude

Voltage difference in microvolts (μV) between a stable reference baseline ($0 \mu\text{V}$) and the peak of the wave.

D - Peak to Peak Amplitude:

Peak to Peak Amplitude :The peak to peak amplitude of an ABR component in microvolts (μv) is typically measured from the peak of the component to the succeeding trough.

- The amplitude depends on the amount of synchronized neural activity and varies with the level of stimulation, hearing loss, neural pathology and age.
- As with absolute latency, accurate peak amplitude may be difficult to determine if the residual noise in the average is too high.

E- Wave V/I amplitude ratio

Amplitude ratio: V/I amplitude ratio > 1

F- Waveform morphology

- It is the clarity, resolution, visual appearance or actual shape of the ABR averaged response.
- Unlike latency and amplitude, the morphology interpretation is entirely subjective.
- Influenced by S/N ratio, stimulus intensity, recording montage, and neuropathology.

Normal variations in ABR wave morphology

A-Wave V is riding on the down- shoulder of wave IV

B-Wave IV is riding on the up-shoulder of wave V

C-Wave IV and V appear as abroad undulation (M configuration)

with wave V amplitude is less than wave IV amplitude

D-Wave V amplitude is greatly reduced than IV

E-Classic IV/V complex

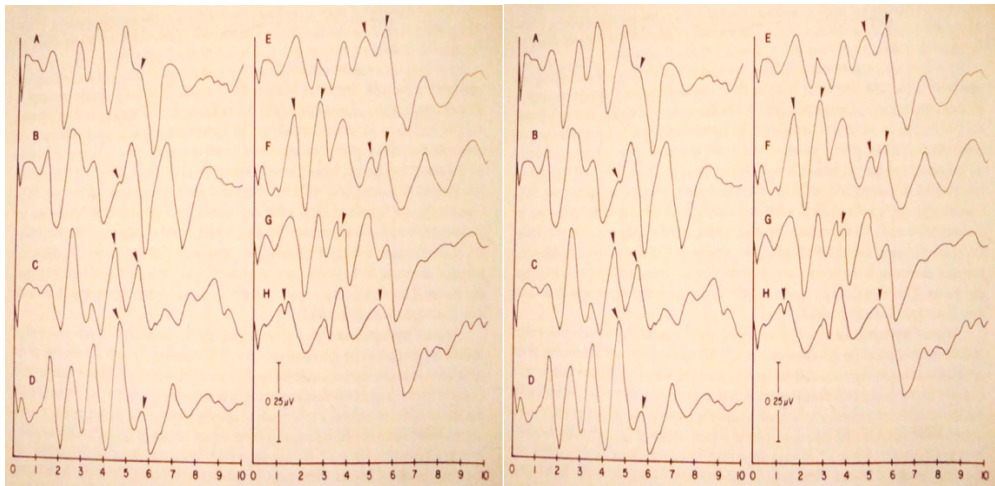


Figure 1.9. Normal variations in ABR wave morphology

F- Bifid wave V

G- Bifid wave III

H- Bifid wave I and fused IV/V

Normative data

- Differences in electrical and electromagnetic field variation between clinical sites as well as heterogeneity in stimulus parameters, electrode placement and transducer type all lead to small but significant differences in wave latency, amplitude and morphology which together can cloud ABR interpretation.

ABR Transducers



Figure 1.10. ABR Transducers.(Image courtesy of James W. Hall, III.)

Insert Advantages

Increase

Interaural Attenuation

Noise reduction

Patient comfort

Aural hygiene

Frequency response

Precise placement

Reduce

Canal collapse

Stimulus artifact

Transducer ringing

Insert Disadvantages

Higher than intended SPLs

Failure to detect mild HL (Minimal effect)

Basic ABR Measures

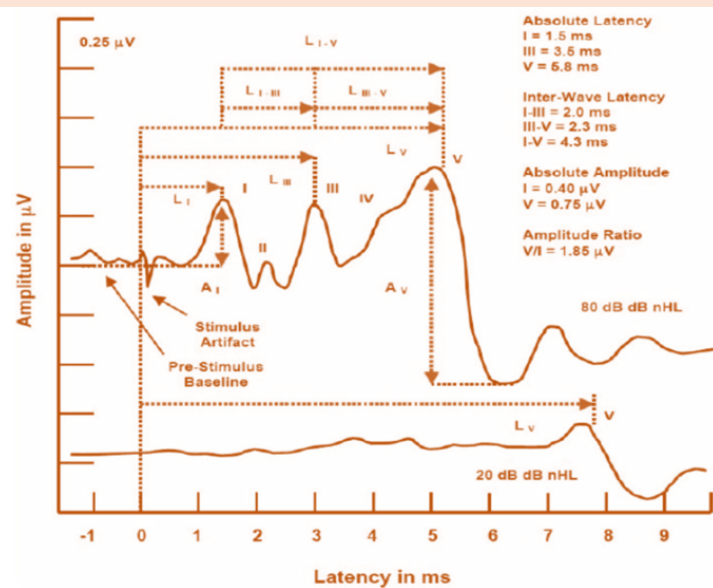
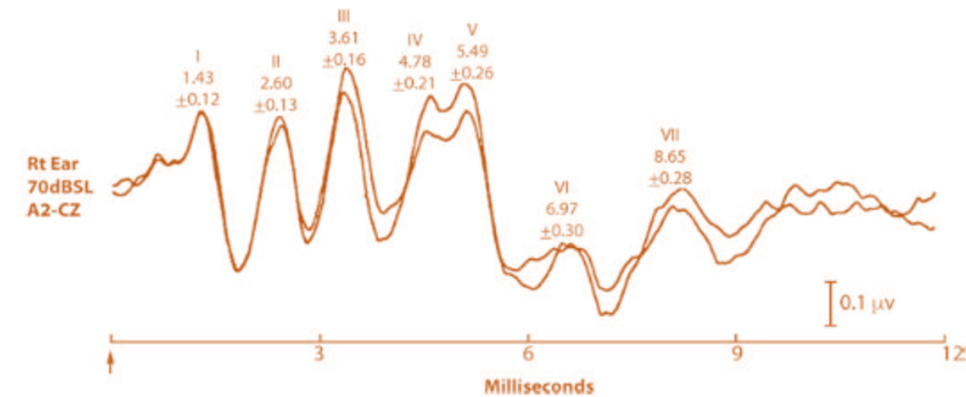


Figure 1.11. Basic ABR Measures.(Image courtesy of James W. Hall, III.)

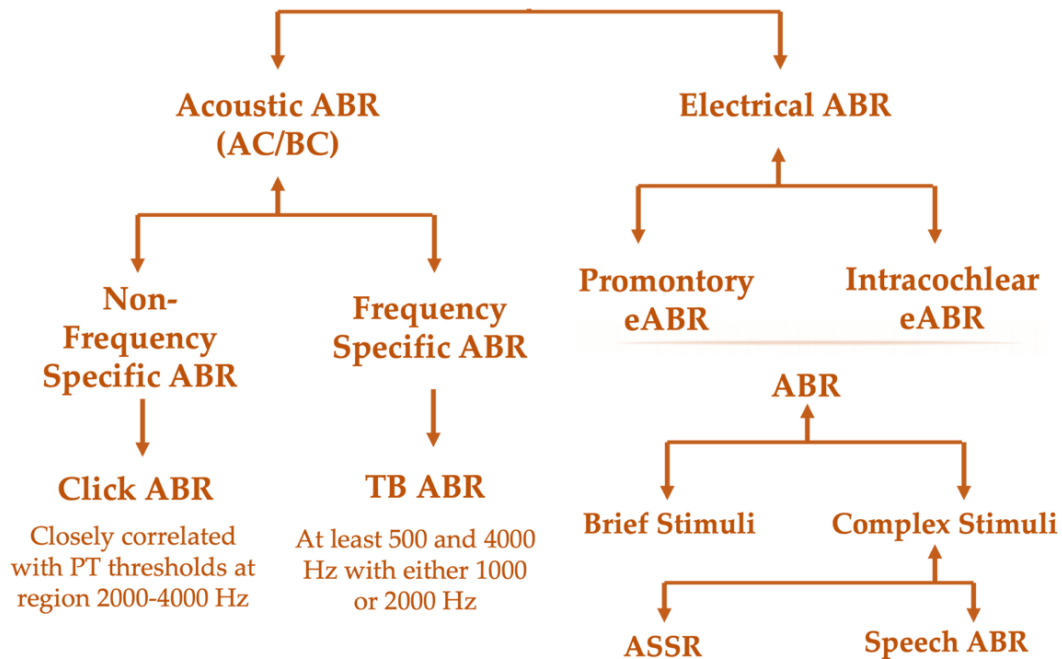
ABR Norms



BAEP components	Mean latencies (msec)	Standard deviation (SD) (msec)	99% Tolerance limit (msec) at 95% confidence level Mean + (2.7 ^a × SD)
Wave I	1.43	0.12	1.75
Wave II	2.60	0.13	2.95
Wave III	3.61	0.16	4.04
Wave IV	4.78	0.21	5.35
Wave V	5.49	0.26	6.19
IPL I-III	2.18	0.12	2.50
IPL III-V	1.88	0.17	2.34
IPL I-V	4.08	0.22	4.67

Figure 1.12. ABR Norms Table 1.1 ABR Norms

Types of ABR



Flowchart 1.1: Types of ABR. (Image courtesy of James W. Hall, III.).

Factors affecting ABR characteristics

Stimulus

- Intensity*
- Frequency*
- Repetition rate*
- Polarity*
- Masking*
- Monaural Versus Binaural Stimulation*

Subject

- Age*
- Sex*
- Intelligence*
- Effect of sleep and sedation*
- Body temperature*
- Effect of medications*
- Type of hearing loss*

ABR and Subjective Factors

Factors	Effects on BAEPs
Gender/women	A. Latencies of waves III and V ↓ B. IPLs I–III and I–V ↓, III–V unchanged C. BAEP amplitude higher D. No gender differences below age 8 years
Age/neonates	A. Latencies of all BAEP peaks ↑ B. All IPLs ↑, I–V ↑ by 1.0 msec
Age/children	A. Wave I reaches adult latency by 6 months B. Wave III, V, and IPLs reach adult values by the age of 2–3 years
Temperature/hypothermia	A. Latencies of all BAEP peaks ↑ B. IPLs I–III, III–V, and I–V ↑ C. Latencies ↑ by 7% per 1 ° C drop D. Wave V recordable up to 20 ° C
Audiogram/sensorineural/conductive hearing deficits	A. Latency of wave I and subsequent peaks ↑, but IPLs remain essentially unchanged B. ↓ amplitude or absence of wave I C. Increasing the click intensity may normalize BAEPs
Subject's state, drugs, alcohol	A. BAEPs unaffected by sleep or change in attention B. BAEPs unaffected by alcohol and sedative/hypnotics drugs

Table 1.2 ABR and Subjective Factors

ABR and Type of HL

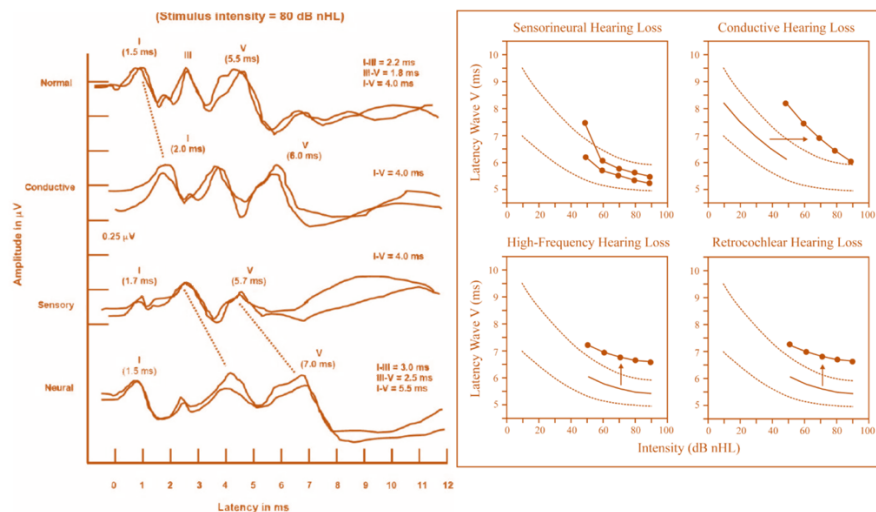


Figure 1.13. ABR and Type of HL

Medications affecting ABR response

Pharmacological agents

Affecting IPL (increase)

Phenytoin (Anticonvulsants)

Lidocaine (Antiarrhythmic)

Alcohol intoxication

No affection

Sedatives

Most of General anesthetics

Neuromuscular blocking agents

Body temperature

Decrease in body temp. increases IPLs.

Explanation: slower neural conduction velocity and synaptic transmission speed in hypothermia.

Because low birth weight infants and comatosed patients are prone to hypothermia, body temp. should be measured prior to ABR

evaluation.

ABR is not affected by:

- *Attention paid to the eliciting stimulus.*
- *Level of arousal*

The stability of the ABR across changes in mental state is an important advantage for ABR over the later components of the auditory evoked potentials.

Effect of stimulus intensity

- *The latencies increase as stimulus intensity decreases.*
- *The amplitudes of the waves decrease as the intensity decreases.*
- *As intensity decreases, the waves prior to Wave V diminish whereas Wave V often remains discernible down to levels approximating the behavioral thresholds for the same stimulus.*

Monaural Versus Binaural Stimulation

(Binaural interaction component of ABR)

- *Binaurally stimulated brainstem responses are larger than monaurally elicited responses by almost two fold.*
- *Binaural stimulation can be used for screenings (the peripheral auditory mechanism is intact in at least one ear)*

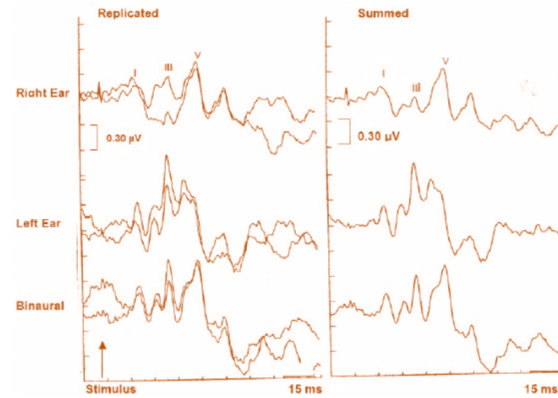


Figure 1.14 ABR waveforms recorded with monaural versus binaural click stimulation.

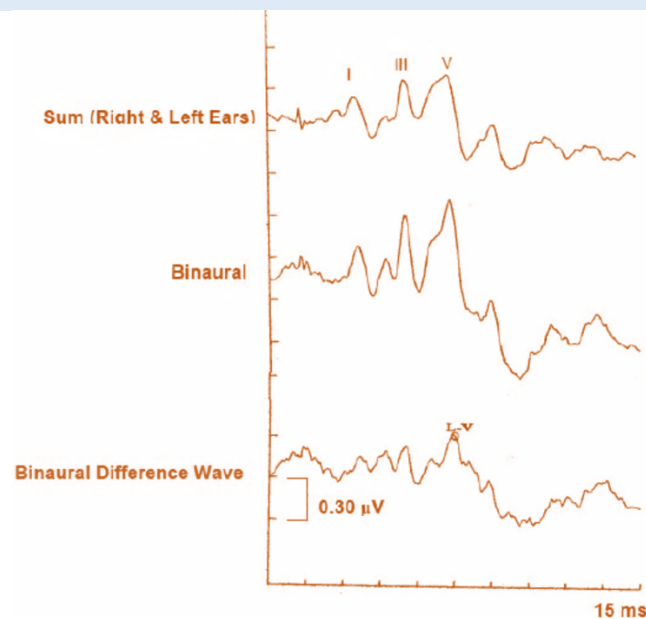


Figure 1.15 Binaural difference wave produced with digital subtraction of ABR waveforms evoked with binaural click stimulation versus the waveforms added digitally for monaural stimulation.

Age effect

ABR in neonates & young children:

- Maturation: 18months
- Wave V/I amplitude ratio less than 1
- Absolute latencies: prolonged compared to adults and decrease gradually due to maturation of cochlea and brainstem.

Older adults:

- *Absolut latencies: prolonged (other studies showed no effect with aging...? Controversy.*
- *Interpeak latency I-III prolonged while III- V not changed.*

Gender effect

- **Females** have slightly shorter wave III and V latencies than males(in adolescence stage).
- **Females** also have larger amplitude of wave V. Explanation: shorter cochlear length of females resulting in greater traveling wave velocity.

Some studies recommended forming normative data for males and females , others found that the differences is not clinically significant.

ABR and Stimulus Factors

Variables	Effects on BAEPs
Decreased click intensity	A. ↑ Latency of all waves with decreasing click intensities B. Latency increases are roughly similar C. IPLs I-III, III-V, or I-V essentially unchanged; IPLs I-V may ↓ D. Waves II and IV disappear first; followed by waves I and III; wave V is last to disappear
Stimulus rate	A. Increasing click rates result in ↑ latencies of all BAEP waves with least effect on wave I B. IPLs I-V ↑ by 0.30–0.45 msec when click rates are increased from 10/sec to 70–80/sec C. Some ↓ or poor definition of all waves except wave V with increasing click rates
Acoustic phase: rarefaction (R) and condensation (C) clicks	A. Wave V least affected by click phase B. ↑ amplitude and ↓ latency of wave I on R clicks C. IPL I-V slightly ↑ with R clicks D. Wave IV enhanced with R clicks E. Wave V enhanced with C clicks F. R-C differences more pronounced in neonates and elderly with hearing deficits
Stimulus mode	A. Binaural stimulation produces ↑ amplitude of waves III and V B. Monaural stimulation is always performed because binaural stimulation may mask interaural asymmetries

Table 1.3 ABR and Stimulus Factors

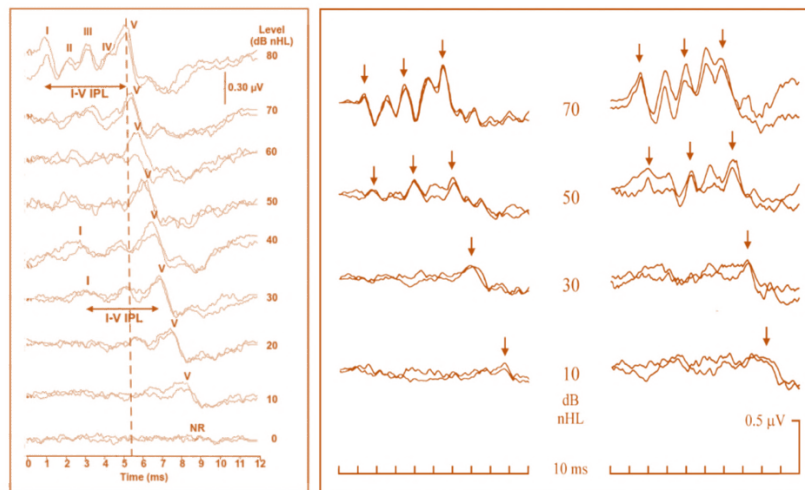


Figure 1.16. ABR and Stimulus Intensity (nHL)

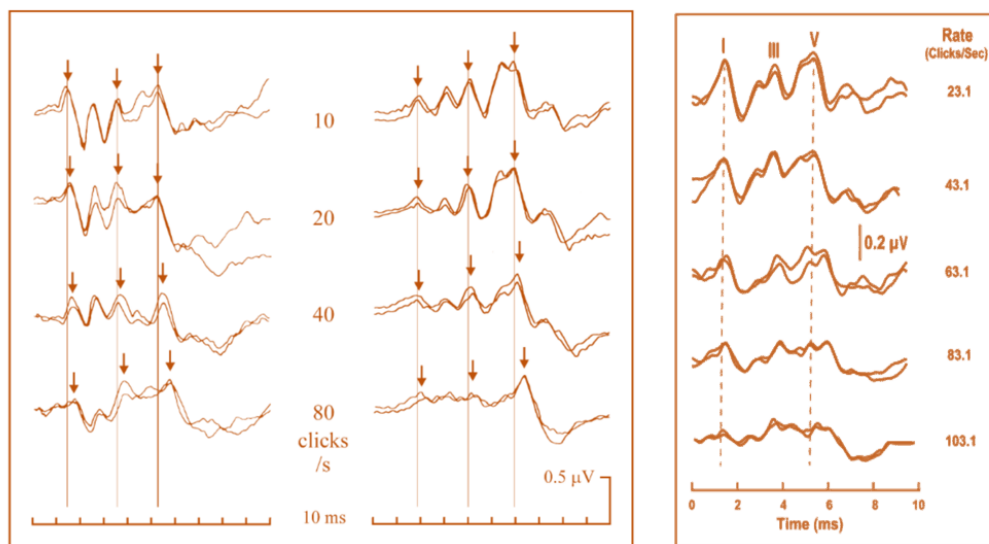


Figure 1.17. ABR and Stimulus Rate

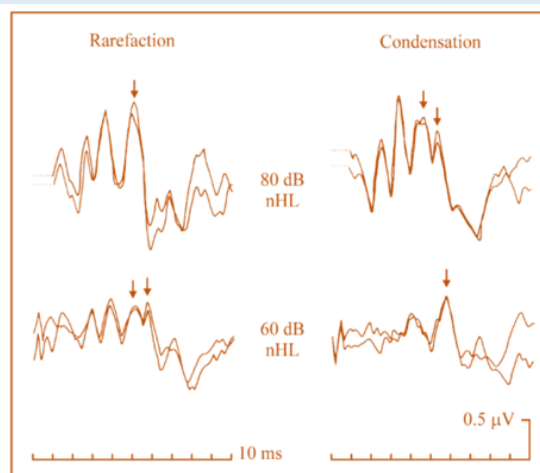


Figure 1.18. ABR and Stimulus Polarity

Where Do Evoked Responses Fit Clinically?

Auditory evoked responses are not replacements for behavioral testing.

*They are **complementary tools**.*

Clinically, they are used to:

- *Estimate hearing sensitivity*
- *Assess neural synchrony*
- *Evaluate integrity of auditory pathways*
- *Support early intervention decisions*

Their real value appears only when they are integrated with:

- *Case history*
- *Otoscopy*
- *Immittance testing*
- *OAEs*
- *Behavioral audiometry when possible*

Objectivity Does Not Mean Certainty

Evoked responses are objective.

But objectivity does not eliminate uncertainty.

A clear waveform does not always mean normal hearing.

An absent response does not always mean severe pathology.

*Evoked responses measure **neural activity**, not perception, understanding, or communication ability.*

This distinction is critical.

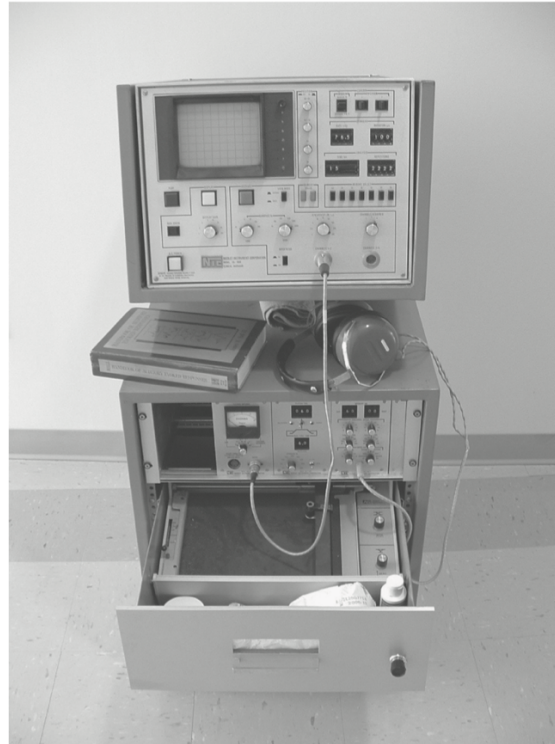


Figure 1.19. Clinical device for recording auditory brainstem (ABR) response known as the Nicolet CA-1000 that contributed in the 1980s to the application of ABR in pediatric and adult populations. The abbreviation CA referred to “clinical averager.” (Image courtesy of James W. Hall, III.).

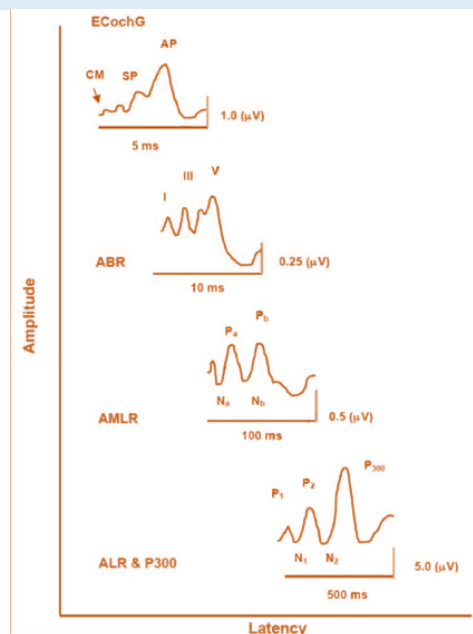


Figure 1.20. Auditory evoked responses recorded clinically including electrocochleography (ECochG), auditory brainstem response (ABR), auditory middle latency response (AMLR), auditory late response (ALR) and P300 response. Note the differences in the latency and amplitude dimensions for different responses (Image courtesy of James W. Hall, III.).

– Clinical Summary

This introductory chapter provides a comprehensive foundation for understanding, measuring, and applying auditory evoked responses (AERs) in clinical practice. Below is a structured summary of the core concepts.

Auditory Evoked Responses (AERs) are essentially the electrical signals generated by the auditory system—from the inner ear to the brain—in response to sound stimuli. They are often referred to as "brain waves" or "evoked potentials."

*These responses are primarily categorized by where they originate in the body and how long they take to appear after a sound is played (**latency**).*

1. Classification of Responses

As sound travels through the ear and up to the brain, it triggers a continuous sequence of electrical events.

Clinicians divide these into specific "windows" of time:

Response Type	Latency (Time)	Anatomical Origin
ECochG (Electrocochleography)	0 – 3 ms	Inner ear (cochlea) and auditory nerve
ABR (Auditory Brainstem Response)	0 – 15 ms	Auditory regions of the brainstem
AMLR (Middle Latency Response)	15 – 50 ms	Regions above the brainstem (rostral)

<i>Response Type</i>	<i>Latency (Time)</i>	<i>Anatomical Origin</i>
<i>ALR (Late Response)</i>	<i>100 – 300 ms</i>	<i>Auditory cortex (higher brain regions)</i>
<i>P300 Response</i>	<i>~300+ ms</i>	<i>Higher cognitive processing centers</i>

Table 1.4 Classification of Responses

2. Key Characteristics: Latency and Amplitude

Two dimensions are critical when analyzing these waveforms:

- ***Latency (X-axis):*** *Measured in milliseconds (ms).*
- *It represents the time delay between the stimulus and the response peak.*
- *Early responses (like ECoG) have very short latencies because they occur close to the ear.*
- *Later responses (like ALR) have longer latencies because the signal must travel further and cross more synapses (neural connections).*
- ***Amplitude (Y-axis):*** *Measured in microvolts.*
- *This represents the "size" of the response.*
- *Interestingly, early responses like the ABR are tiny (about), while cortical responses like the ALR can be much larger because millions more neurons are involved in the cortex than in the auditory nerve.*

3. The Influence of Sound Intensity

The intensity (loudness) of the sound used to trigger the response has two predictable effects:

1. **Direct Relationship with Amplitude:** Louder sounds produce larger (higher amplitude) responses.
2. **Indirect Relationship with Latency:** As the sound gets louder, the response appears faster (shorter latency). As the sound gets softer, the latency increases.

4. How They Are Recorded

To record these brain waves, clinicians use **acoustic transducers** to deliver sound and **electrodes** to detect electrical activity.

- **Transducers:** Usually **insert earphones** (foam tips that fit in the ear canal) or bone vibrators.
- **Electrodes:** Small sensors placed on the scalp (often the forehead and near the ears) that "listen" for the tiny electrical charges produced by the auditory system.

Key Points

ABR is

Small amplitude, Scalp recorded, Far field electrical potentials, of the auditory pathways, that occur within 10—15 ms,

ABR needs

Proper averaging, Proper Time window.

- Auditory evoked responses objectively measure neural activity in response to sound.
- They are essential when behavioral responses are unreliable or unavailable.

- *Evoked responses do not replace behavioral audiometry.*
- *Interpretation—not recording—is the true clinical challenge.*

Common Mistakes

- *Treating evoked responses as definitive proof of hearing status.*
- *Ignoring patient age, state, or test conditions.*
- *Using evoked tests in isolation.*
- *Writing reports that describe results without clinical meaning.*

Red Flags

- *Poor waveform replicability*
- *Interpretation without age-appropriate norms*
- *Ignoring discrepancies between evoked and behavioral findings*

Pitfalls

- *Overconfidence in objectivity*
- *Ignoring patient state and recording conditions*
- *Treating evoked responses as standalone diagnostic tools*

Evidence-Based & International Guidelines Best-Practice Principles

- *Evoked responses must be part of a **cross-check test battery**.*
- *Test conditions, reliability, and limitations must be documented.*

Ethics

- *Overreassurance can delay intervention.*

Take-Home Messages

- *Evoked responses are powerful tools.*
- *Objectivity does not replace judgment.*

What This Test CANNOT Tell You

- *Does **NOT** measure speech understanding*

- Does **NOT** predict language outcome
- Does **NOT** replace behavioral audiometry

ENT Will Ask You This

“So... what does this change in management?”

Be ready with a clear answer—or say honestly that more data is needed.

1-Minute Self-Audit (Before Signing the Report)

- *Did I state limitations clearly?*
- *Did I integrate history and cross-check tests?*

Clinical Confidence Scale

- **High:** Integrated data, consistent findings
- **Moderate:** Some uncertainty → follow-up planned
- **Low:** Conflicting data → no definitive conclusion.



CHAPTER

2

What Are Auditory Evoked Responses?

Auditory evoked responses were never meant to stand alone.

They are designed to work within a system that includes:

- *History*
- *Otoscopy*
- *Immittance*
- *OAEs*
- *Behavioral results when available*

Only when integrated do they become clinically powerful.

*Before learning types, waveforms, or protocols, you must understand **what evoked responses are—and what they are not.***

Overview of the Auditory System

*The auditory system is organized as a **hierarchical pathway**, converting acoustic energy into neural signals and transmitting them centrally. Evoked responses reflect activity at different levels of this pathway depending on response latency.*

The system can be broadly divided into:

- *Peripheral auditory system*
- *Brainstem pathways*
- *Thalamic and cortical structures*

Peripheral Auditory Mechanisms

Outer Ear

The outer ear serves as a sound collection and resonance system.

While it does not generate evoked responses, it influences stimulus intensity and spectral characteristics reaching the cochlea.

Middle Ear

The middle ear acts as an impedance matching system. Its primary relevance to evoked responses lies in:

- *Transmission efficiency*
- *Conductive delay effects*
- *Elevation of stimulus levels required to elicit responses*

Middle ear dysfunction alters evoked response thresholds without directly affecting neural timing.

Cochlea

The cochlea is responsible for converting mechanical vibration into neural activity. Key physiologic processes include:

- *Frequency specific mechanical tuning*
- *Inner hair cell transduction*
- *Activation of auditory nerve fibers*

*Evoked responses depend on **cochlear output quality**, even when the site of measurement is central.*

Auditory Nerve Physiology

The auditory nerve transmits encoded neural signals from the cochlea to the brainstem. Critical features include:

- *Phase locked firing at lower frequencies*
- *Population synchrony at stimulus onset*
- *Rapid conduction velocity*

*Evoked responses primarily reflect **onset synchrony** rather than sustained neural firing.*

Brainstem Auditory Pathways

After leaving the auditory nerve, neural signals travel through multiple brainstem nuclei. These nuclei contribute collectively to short latency evoked responses.

Key characteristics include:

- *Bilateral projection patterns*
- *Sequential synaptic transmission*
- *Progressive integration of neural activity*

Neural Synchrony and Timing

*A central concept emphasized in this chapter is **neural synchrony**.*

For an evoked response to be visible:

- *Large populations of neurons must fire simultaneously*
- *Timing must be consistent across stimulus presentations*
- *Temporal dispersion must be minimal*

Disruption of synchrony reduces waveform clarity even when neural structures are intact.

Latency as a Physiologic Marker

Latency reflects the time required for neural signals to travel from stimulus onset to recording site. Latency is influenced by:

- *Conduction velocity*
- *Synaptic delay*
- *Pathway length*
- *Neural integrity*

Latency patterns provide more physiologic information than amplitude alone.

Maturation and Myelination

Neural conduction efficiency improves with maturation due to myelination and synaptic refinement. This explains:

- *Prolonged latencies in infants*
- *Progressive latency shortening with age*
- *Age dependent normative values*

Understanding maturation is essential for pediatric interpretation.

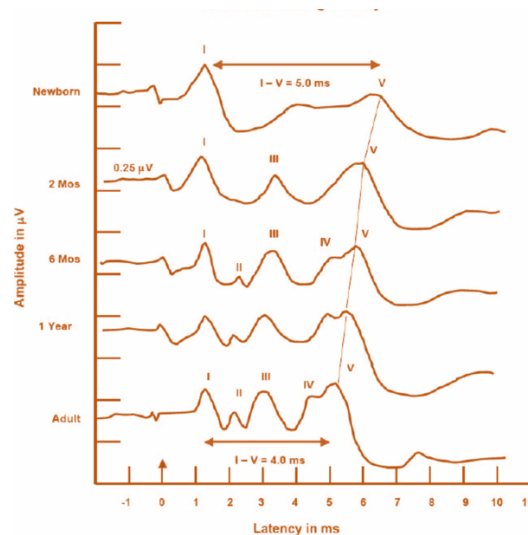


Figure 2.1. Effect of developmental age on ABR waveform latency and morphology in infants (Image courtesy of James W. Hall, III.).

Clinical Implications

Physiologic and anatomic knowledge allows clinicians to:

- *Distinguish peripheral from neural pathology*
- *Understand latency shifts caused by conductive dysfunction*
- *Recognize patterns consistent with neural dyssynchrony*
- *Avoid attributing normal maturational findings to disease*

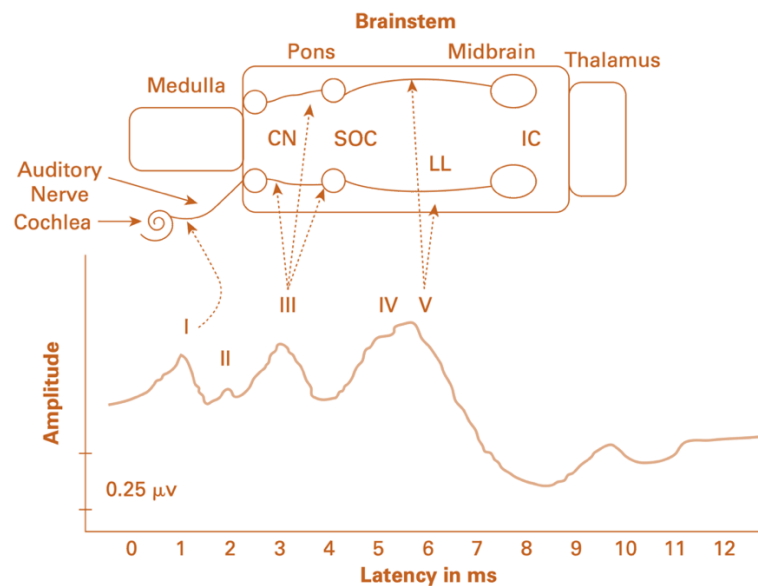


Figure 2.2 .Anatomical generators of the auditory brain- stem response (ABR). The relation between ABR components and auditory structures is described in the text. Abbreviations are as follows: CN = cochlear nucleus SOC = complex LL = superior olivary lateral lemniscus IC = inferior colliculus(Image courtesy of James W. Hall, III.).

– Clinical Summary

*Auditory evoked responses are electrical activities within the auditory system (brain waves) stimulated by sound. They are categorized primarily by **latency** (the time between the sound and the response) and **anatomic origin**.*

Response Type	Latency Range	Anatomic Origin
ECochG	0 – 3 ms	Inner ear (Cochlea) & Auditory Nerve
ABR	0 – 15 ms	Auditory Brainstem
AMLR	15 – 50 ms	Rostral to brainstem (Thalamus/Cortex)
ALR	50 – 300 ms	Auditory Cortex
P300	300+ ms	Cortical / Cognitive processing

Table 2.1

Key Principle: AERs occur in a continuous, rapid sequence. While we categorize them as discrete, they represent a seamless flow of neural activity from the ear to the highest levels of the brain.

The Science of Measurement: Signal Averaging

1. **Amplification:** Boosting the signal (often 100,000 times).
2. **Signal Averaging:** Presenting a sound thousands of times. Since the brain's response is "time-locked" to the sound, it adds up and grows, while random background noise cancels itself out over time.

Common Mode Rejection (CMR): A process where the amplifier subtracts electrical activity that is identical at two electrode sites (noise), leaving only the unique activity (the response).

Essential Test Parameters

Successful measurement depends on the "Evidence-Based Protocol," which balances two sets of parameters:

Stimulus Parameters (The "Input")

- **Transducer:** Devices like **Insert Earphones (ER-3A)** are preferred because they prevent ear canal collapse and increase inter-aural attenuation.
- **Type:** Clicks (for broad brainstem activation) or Tone Bursts (for frequency-specific thresholds).
- **Polarity:** Rarefaction (diaphragm moves out) or Condensation (moves in). Polarity is critical for diagnosing Auditory Neuropathy.
- **Rate:** Fast rates save time; slow rates (odd numbers like 21.1/sec) avoid interference from 60 Hz power lines.

Acquisition Parameters (The "Recording")

- **Electrodes:** Surface sensors (disc or disposable) placed on the scalp (e.g., Forehead Fz and Earlobe Ai).
- **Filters:** High-pass and Low-pass filters remove noise outside the frequency of the response.
- **Analysis Time (Epoch):** The window of time the computer "looks" for the response (e.g., 15 ms for ABR).

Clinical Significance

Why use AERs instead of a standard "raise your hand" hearing test?

- **Non-behavioral:** AERs do not require the patient to be awake or cooperative. They are essential for **newborns**, **comatose patients**, and the **difficult-to-test**.

- **Universal Screening:** Automated ABR technology allows every baby born to be screened for hearing loss at birth.
- **Site-Specificity:** AERs can pinpoint exactly where a problem is (cochlea vs. nerve vs. brainstem), which behavioral tests cannot always do.
- **Intra-operative Monitoring:** Protecting the auditory nerve during delicate brain surgeries.

The "Art" of the Clinician

While AERs are often called "objective," the text emphasizes that they are a blend of **Science and Art**.

- **Thinking on your feet:** A clinician must constantly adjust protocols based on a patient's state (e.g., if a baby wakes up, switching to a "Worst Case Scenario" plan to get the most vital data first).
- **Troubleshooting:** Identifying when a "flat line" is actual hearing loss versus a technical error like a loose electrode or electrical interference from a hospital incubator.

Key Points

- Auditory evoked responses record **neural activity**, not perception.

Golden Rules

If you remember only one rule from this chapter, remember this:

- ***Evoked responses describe neural reactions—not hearing experience.***

Common Mistakes

- Assuming evoked responses measure understanding or speech perception.

Red Flags

- Results interpreted without integration with other tests.
- Interpretation without consideration of maturation

Ethics

- Clinicians must communicate limitations honestly.

Documentation

- Document **what was measured** clearly.
- Include limitations and recommendations

Medico-Legal Pitfalls

- Missing documentation of limitations.
- Reports misinterpreted by non-audiologists.

Final Clinical Message

Auditory evoked responses tell us **how the auditory system reacts**.

They do not tell us **what the patient understands**.

That difference matters.

Take-Home Messages

- Neural synchrony is essential for waveform generation

What This Test CANNOT Tell You

- Speech understanding
- Language outcome
- Cognitive processing



CHAPTER

3

Why Are Auditory Evoked Responses Important?

Some patients can tell us what they hear.

Others cannot.

Yet decisions must still be made.

Auditory evoked responses exist for that exact moment—

when audiology must act without relying on behavior.

Their importance is not technical.

*It is **clinical**.*

When Waiting Is Not an Option

In infants and young children, waiting for behavioral responses means losing time.

And time, in audiology, is never neutral.

Delayed diagnosis leads to delayed intervention.

Delayed intervention affects language, learning, and social development.

Auditory evoked responses allow early action

when waiting would cause harm.

Modern audiology is multidisciplinary and outcome-driven.

Evoked responses play a central role in:

- *Newborn hearing screening follow-up*
- *Pediatric diagnostic pathways*
- *Neurodiagnostic assessment*
- *Pre-intervention planning*

Their role continues to expand.

So does responsibility

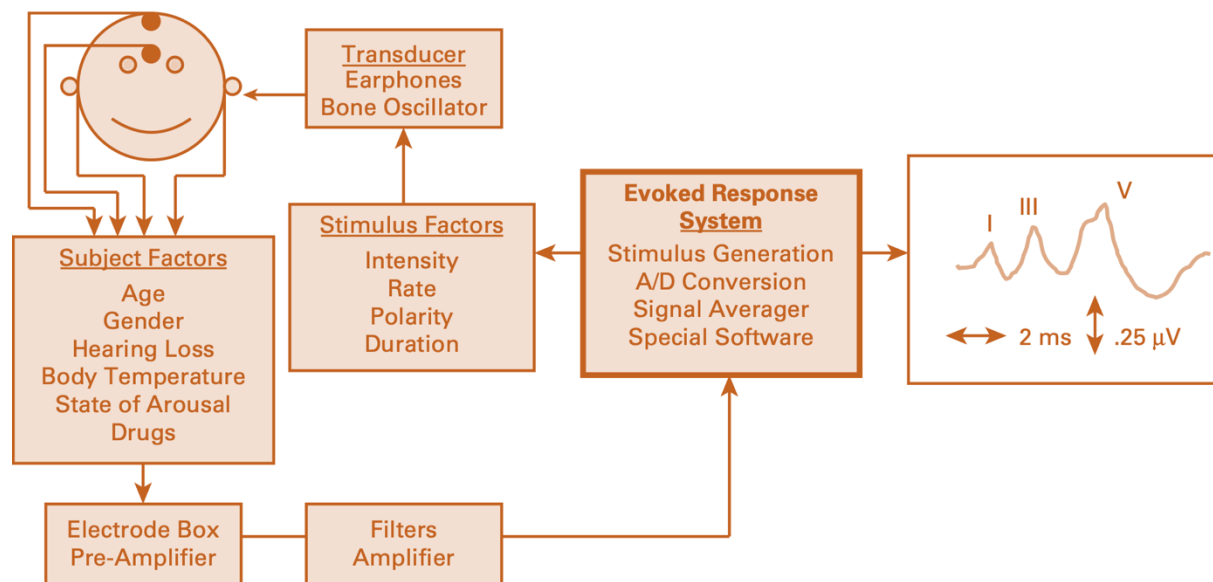


Figure 3.1.Diagram of major steps in measurement of the auditory brainstem response (ABR) including the types of stimuli, transducers used to present the stimuli, location of electrodes on the scalp and ears, subject factors influencing the ABR, and other components of an ABR system. An ABR - waveform is shown on the right side of the figure. (Image courtesy of James W. Hall, III.).

– Clinical Summary

Auditory evoked responses (AERs) are a cornerstone of modern audiology because they provide objective data that behavioral "hand-raising" tests simply cannot. While behavioral audiometry is useful for

cooperative adults, AERs are essential for populations where active participation is impossible or unreliable.

1. Assessment of Non-Behavioral Patients

The most significant advantage of AERs is that they do not require an alert, cooperative, or even conscious patient. This makes them the "gold standard" for:

Infants and Toddlers: Newborns cannot tell you if they hear a sound. AERs allow for hearing assessment within hours of birth.

Difficult-to-test Children: This includes patients with developmental delays, autism, or cognitive impairments.

Surgical and Trauma Patients: Monitoring hearing during brain surgery or assessing comatose patients with head injuries.

Malingers: Identifying individuals who may be faking or exaggerating hearing loss for insurance or legal reasons.

2. Universal Newborn Hearing Screening (UNHS)

The development of automated ABR (AABR) technology in the mid-1980s revolutionized pediatric care. It allows non-professionals (such as nursing staff) to screen large numbers of babies quickly. This has led to the early identification of hearing loss, allowing for intervention (like hearing aids or cochlear implants) during the critical window for language development.

3. Superior Sensitivity and Site-Specificity

AERs offer a level of diagnostic "mapping" that behavioral tests lack. Because we know exactly which anatomical structures generate specific waves, we can pinpoint the site of a problem.

Neural Dysfunction: AERs can detect issues in the auditory nerve (8th cranial nerve) or brainstem that might be missed by a standard pure-tone test.

Structural Localization: If a response is missing or delayed at a specific millisecond marker, clinicians can determine if the dysfunction is in the **cochlea**, the **auditory nerve**, or the **brainstem**.

4. Monitoring Maturation and Intervention

AERs, particularly cortical responses, are used to document how a child's central nervous system matures after receiving intervention. By measuring these "brain waves" over time, clinicians can objectively see if a hearing aid or cochlear implant is successfully stimulating the brain and promoting neural development.

Pitfalls

- Failure to plan follow-up
- Evoked responses should be integrated into a **multimodal test battery**.

Ethics

- Early decisions shape lifelong outcomes.

Report Writing

- Use language that guides action without causing alarm.
- Avoid absolute diagnostic statements.

Medico-Legal Pitfalls

- Irreversible decisions based on incomplete data.



CHAPTER

4

How Are Auditory Evoked Responses Measured?



Auditory evoked responses are not captured by chance.

*They are **measured**, carefully and intentionally.*

What we record is not sound.

And not hearing.

*But the nervous system's **electrical reaction** to sound.*

Measuring that reaction requires control, patience, and understanding.

The Basic Idea

A sound stimulus is presented.

The auditory system responds.

Electrodes detect tiny electrical signals generated by neural activity.

These signals are extremely small—

often buried within much larger biological and environmental noise.

*Measurement, therefore, is about **revealing the signal** without creating false certainty.*

Electrodes: Listening to the Nervous System

Electrodes do not stimulate the ear.

They listen.

Placed on the scalp and earlobes or mastoids, electrodes:

- *detect voltage changes*
- *do not feel pain*
- *do not alter hearing*

Their role is passive—but critical.

*Poor electrode placement or impedance control
can distort results before interpretation even begins.*

Stimulus Presentation

Evoked responses depend on controlled stimulation.

Key stimulus characteristics include:

- *Type (click, tone burst, chirp)*
- *Intensity*
- *Rate*
- *Polarity*

Each parameter influences:

- *which neural populations respond*
- *how synchronized the response appears*

*Measurement without understanding stimulus design
leads to misinterpretation.*

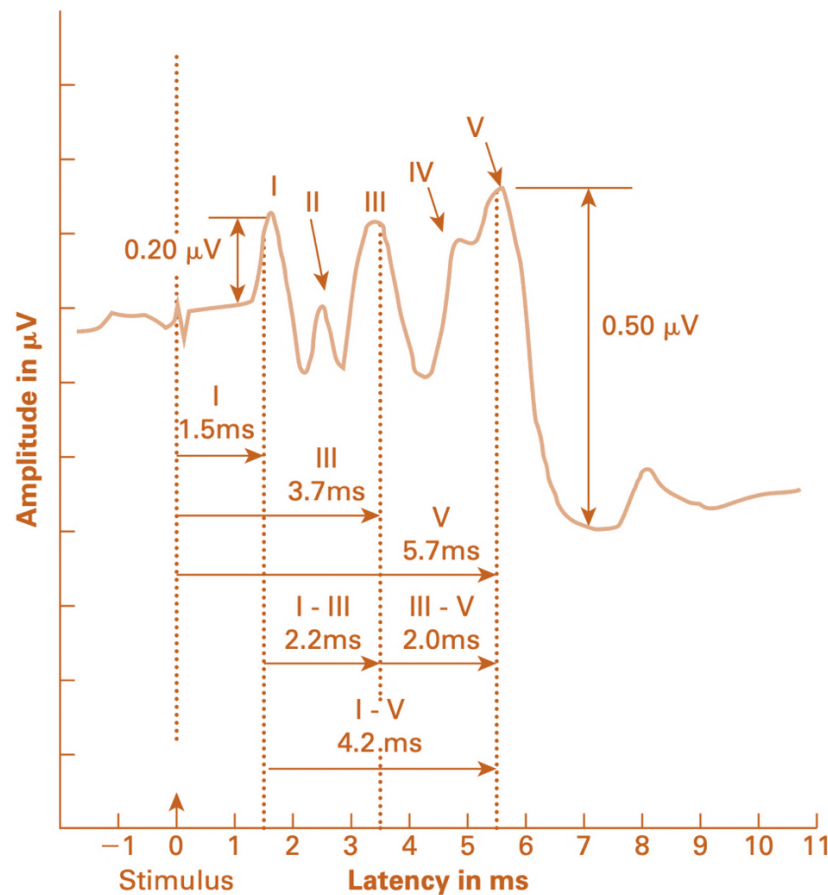


Figure 4.1. Calculations made in analysis of the auditory brain stem response, including latency and amplitude of wave I, wave III, wave V, and - inter-wave latency values. An explanation of ABR analysis is provided in the text. (Image courtesy of James W. Hall, III.).

– Clinical Summary

Measuring auditory evoked responses (AERs) is a sophisticated process that translates sound-evoked neural activity into visible brain waves.

The procedure involves capturing incredibly tiny electrical signals—often less than a millionth of a volt—and separating them from the "noise" of general brain and muscle activity.

1. The Measurement Pathway

The measurement follows a specific sequence from the moment a sound is presented to the point where a waveform appears on the computer screen.

Stimulation: *A sound (click or tone) is delivered via a transducer, such as insert earphones.*

Detection: *Surface electrodes placed on the scalp detect the resulting electrical activity generated by the ear, auditory nerve, and brain.*

Pre-amplification: *The tiny signal travels through wires to a pre-amplifier, which boosts the activity (often by 100,000 times) so it can be processed.*

Filtering & Conversion: *Filters remove unrelated electrical noise (like power line hum), and an analog-to-digital converter prepares the data for the computer.*

Processing: *Specialized software uses signal averaging to clarify the response.*

2. Understanding Latency and Waveforms

*Because we cannot place electrodes directly inside the brain in a clinical setting, we rely on **latency**—the timing of the response—to identify where the signal is coming from.*

Latency: *The time (in milliseconds) between the stimulus and the neural peak.*

Waveform: *The visual pattern of peaks and valleys. By calculating the latency of these peaks, clinicians can identify the generator:*

Short Latency (0–10 ms): *Inner ear and auditory nerve (e.g., ECochG, ABR).*

Middle Latency (15–50 ms): Auditory brainstem and lower subcortical areas.

Long Latency (100–500 ms): Auditory cortex.

3. Signal Averaging: Finding the Signal in the Noise

Auditory brain activity is measured in **microvolts (μV)**. For comparison:

Cortical responses: 5 to 10 μV .

ABR waves: Often less than 0.5 μV .

The "noise" (muscle tension, background brain activity, room electricity) is much larger than the auditory signal. To improve the

Signal-to-Noise Ratio (SNR), we use **Signal Averaging**.

How Signal Averaging Works:

The system presents hundreds or thousands of sounds.

The neural response is **time-locked** (it happens at the exact same time after every sound). When added together, these responses strengthen.

The noise is **random**. For every positive voltage recorded, there is eventually a negative one that cancels it out.

The result is a clean waveform that represents the actual auditory response.

4. Clinical Setup

A typical setup for a procedure like the Auditory Brainstem Response (ABR) requires specific placement of sensors to ensure accurate recording.

Electrodes: Usually placed high on the forehead and near or on the ears (mastoid or earlobe).

Transducers: Insert earphones are the clinical standard, using foam cushions to deliver sound directly into the ear canal.

Key Points

- Evoked responses measure **electrical neural activity**, not sound.

Common Mistakes

- Ignoring electrode impedance and placement.
- Interpreting waveforms without checking test conditions.

Red Flags

- High or unequal electrode impedance.
- Excessive noise mistaken for neural response.
- Misinterpreting artifacts as responses

Documentation

- Document electrode sites and impedance.
- Record stimulus parameters used.
- Note patient state and cooperation.

Medico-Legal Pitfalls

- Decisions based on poorly documented recordings.

Take-Home Messages

Transparency protects patients and clinicians.



CHAPTER

5

Factors in Measurement of Auditory Evoked Responses

Evoked responses are not fixed truths.

*They are **products of conditions**.*

*Change the conditions,
and the response changes.*

*Understanding the factors that influence measurement
is what separates accurate assessment
from misleading certainty.*

Why Factors Matter

*Two clinicians can test the same patient
and record different results.*

*Not because one is right and the other is wrong,
but because measurement is sensitive.*

Auditory evoked responses are influenced by:

- *the patient*
- *the equipment*
- *the environment*

- *and the clinician's choices*

Ignoring these factors means interpreting noise as meaning.

Patient-Related Factors

The patient is not a passive participant.

Age, state, and physiology all influence responses.

Key patient factors include:

- *Age and neural maturation*
- *Sleep or alertness*
- *Muscle activity and movement*
- *Middle-ear status*

*A perfect protocol on an unstable patient
produces unstable data.*

Stimulus-Related Factors

What you present determines what you record.

Stimulus characteristics such as:

- *Type*
- *Intensity*
- *Rate*
- *Polarity*

directly affect neural synchrony and waveform appearance.

*Using the wrong stimulus for the wrong question
leads to correct-looking but irrelevant results.*

Recording-Related Factors

Measurement depends on how signals are captured.

Important recording factors include:

- *Electrode placement*
- *Electrode impedance*
- *Number of averages*
- *Filtering settings*

*These factors do not change the auditory system—
they change **what you see**.*

Environmental Factors

Evoked responses are small.

Noise is large.

*Electrical interference, room setup, and equipment grounding
can all distort recordings.*

Environmental control is not optional.

It is part of measurement.

Clinician-Related Factors

The clinician is the most powerful variable.

Choices about:

- *when to stop averaging*
- *when to repeat*
- *when to accept a response*

shape the final result.

*Clinical judgment begins during measurement,
not after it.*

*High quality auditory evoked responses are the result of precise
recording principles and appropriate instrumentation.*

Basic Principles of Evoked Potential Recording

Low-Amplitude Neural Signals

Auditory evoked responses are extremely small electrical signals, typically measured in microvolts.

These signals are embedded within ongoing EEG activity that is much larger in amplitude.

Recording systems must therefore amplify neural responses while minimizing unwanted noise.

Time-Locked Averaging

*A defining principle of evoked response recording is **time locking**.*

Neural activity that consistently follows stimulus onset is preserved through averaging, while random background EEG activity is reduced.

Averaging relies on:

- Repeated stimulus presentation*
- Consistent neural timing*
- Stable recording conditions*

Without time locking, evoked responses cannot be separated from noise.

Signal-to-Noise Ratio

The quality of an evoked response depends largely on the signal-to-noise ratio. This ratio can be improved by:

- Increasing the number of stimulus presentations*
- Reducing physiologic noise such as muscle activity*
- Optimizing electrode placement and impedance*
- Controlling the recording environment*

Poor signal-to-noise ratio limits interpretability regardless of stimulus intensity.

Instrumentation Components

Stimulus Generation System

The stimulus generator controls:

- *Type of stimulus*
- *Intensity*
- *Rate*
- *Polarity*
- *Timing precision*

Accurate stimulus timing is critical because latency measurements depend directly on stimulus onset consistency.

Transducers

Transducers deliver acoustic energy to the ear and influence both stimulus timing and spectral content. Common transducers include:

- *Insert earphones*
- *Supra-aural headphones*
- *Bone conduction vibrators*

Insert earphones are often preferred due to reduced stimulus artifact and improved interaural attenuation.

Electrodes

Surface electrodes detect voltage differences generated by neural activity. Key considerations include:

- *Electrode type and quality*
- *Proper skin preparation*

- *Stable attachment throughout testing*

Electrode integrity directly affects noise levels and waveform stability.

Amplifiers

Amplifiers increase the magnitude of neural signals so they can be visualized and analyzed. Effective amplification requires:

- *High gain*
- *Low internal noise*
- *Stability across recording sessions*

Over-amplification can distort signals, while under-amplification may obscure true responses.

Filters

Filters are used to limit the frequency range of recorded signals.

Appropriate filtering:

- *Preserves waveform morphology*
- *Reduces low-frequency drift and high-frequency noise*
- *Maintains latency accuracy*

Improper filter settings can distort waveforms and alter latency measurements.

Averaging and Analysis Systems

Averaging systems sum neural responses across multiple trials.

Modern systems also provide:

- *Artifact rejection*
- *Replication displays*
- *Digital storage for later comparison*

Automated features assist the clinician but do not replace visual inspection and judgment.

Electrode Montage and Placement

Electrode configuration determines which neural activity is emphasized. Typical montages include:

- *High forehead or vertex active electrode*
- *Reference electrodes near the ears*
- *A common ground electrode*

Balanced and low electrode impedances are essential to minimize noise.

Artifact Sources and Control

Common artifact sources include:

- *Muscle activity*
- *Eye movement*
- *Poor electrode contact*
- *Electrical interference from equipment*

Artifact rejection systems reduce contamination, but excessive rejection may also eliminate true neural responses.

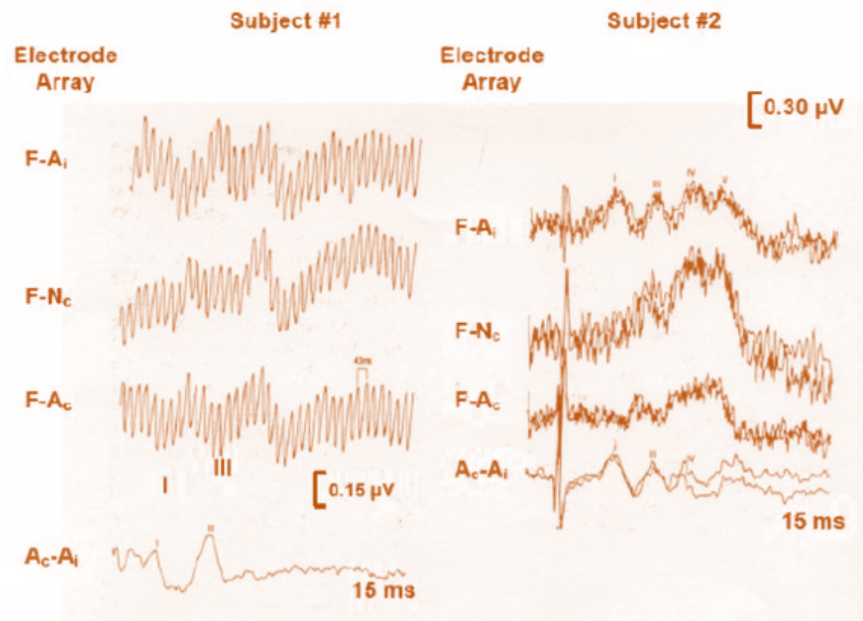


Figure 5.1. Electrical artifact recorded with different electrode arrays from two different patients during ABR assessments in electrically hostile environments. (Image courtesy of James W. Hall, III.).

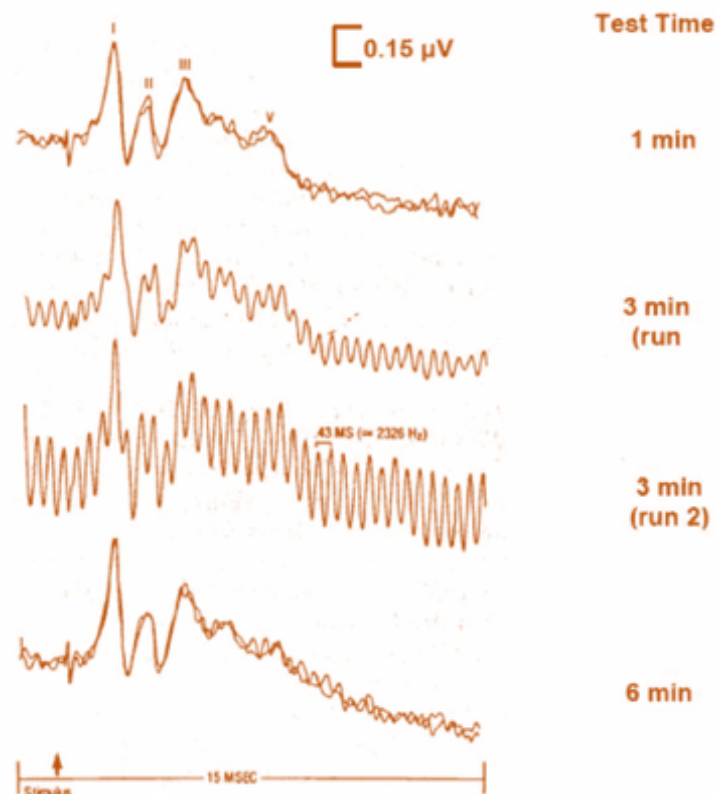


Figure 5.2. Electrical artifact recorded at different times during ABR recording of a patient in an electrically hostile environment, in this case a neuro-intensive care unit. (Image courtesy of James W. Hall, III.).

Replication as a Validity Criterion

Replication is the most important criterion for confirming true evoked responses. A valid response must:

- Appear consistently across repeated recordings*
- Maintain similar morphology and latency*
- Remain time locked to stimulus onset*

Responses that cannot be replicated should not be interpreted.

Calibration and System Integrity

Accurate evoked response testing depends on regular system calibration. Calibration ensures:

- Accurate stimulus intensity*
- Reliable timing*
- Consistent performance across sessions*

Uncalibrated systems compromise both diagnostic accuracy and medico-legal defensibility.

– Clinical Summary

Clinical measurement of auditory evoked responses (AERs) is influenced by three main categories of factors

Subject Factors, Stimulus Parameters, and Acquisition Parameters.

Understanding the interaction between these variables is essential for accurate diagnosis and reliable data collection.

1. Subject Factors

The patient's biological and physiological state can significantly alter AER results. These factors must be accounted for to distinguish between normal variation and actual pathology.

Age and Gender: Age affects all responses due to the maturation of the central nervous system; gender primarily influences ABR latencies (males typically have longer latencies).

Physiological State: Body temperature and state of arousal (awake vs. asleep) are critical. While sleep doesn't affect early responses like ABR, it can suppress or abolish later cortical responses (ALR and P300).

Muscle Artifact: Excessive movement or jaw/neck tension creates "noise" that can drown out the tiny neural signals.

Pathology: The condition of the middle ear, cochlea, and auditory nerve directly dictates the morphology of the recorded wave.

2. Stimulus Parameters

These are the characteristics of the sound used to evoke the response. Choosing the wrong parameters can result in a "flat line" even in a patient with normal hearing.

Transducer: Usually insert earphones, supra-aural headphones, or bone oscillators.

Stimulus Type: Clicks (brief, broad-frequency) are used for ABR, while **Tone Bursts** are used for frequency-specific testing.

Duration and Rate: If a stimulus is too long (e.g., a slow-rising tone), it won't produce the synchronous neural firing needed for an ABR. Conversely, if the rate is too fast (e.g., 20/sec), it will "fatigue" the neurons needed for a Late Response (ALR), which requires a slow rate (e.g., 1/sec).

Intensity: Higher intensity leads to larger amplitudes and shorter latencies.

3. Acquisition Parameters

These parameters determine how the electrical activity is captured and processed by the equipment.

Electrodes: The type (metal disc vs. disposable) and location (the "array") are crucial. Common sites include the high forehead (Fz) and the earlobes (Ai).

Analysis Time (Epoch): This is the "window" of time the computer records after each sound. For ABR, it is typically 10–15 ms; for cortical responses, it must be 500 ms or longer.

Filtering and Amplification: Filters remove unwanted noise (like 60 Hz power line hum), while amplifiers boost the tiny neural signals (often by 100,000 times) so they can be seen.

Sweeps: This is the number of stimuli presented. More "sweeps" improve the signal-to-noise ratio by averaging out random background noise.

4. The "Objective" Nature of AERs

AERs are often called **objective** because they don't require the patient to raise their hand or provide a behavioral response. However, the interpretation of the result remains **subjective**, relying on the clinician's skill to identify wave components and judge the reliability of the recording.

Key Points

- Evoked responses are influenced by multiple interacting factors.

- *Patient, stimulus, recording, and environment all affect results.*
- *Clinician decisions during testing shape outcomes.*

Common Mistakes

- *Ignoring patient state during testing.*
- *Using default stimulus settings blindly.*
- *Trusting waveforms without reviewing recording conditions.*

Red Flags

- *Inconsistent responses without explanation.*
- *Interpretation without confirming replication*

Pitfalls

- *Interpreting non-replicated waveforms*
- *Ignoring poor electrode impedance*
- *Using inappropriate filter settings*

Final Clinical Message

- *Replication is more important than waveform beauty*
- *Good recording technique precedes good interpretation*
- *Noise control is as critical as stimulus selection*
- *Automated systems assist but do not think clinically*
- *Auditory evoked responses are low-amplitude, time-locked neural signals*
- *Signal-to-noise ratio determines waveform quality*
- *Replication confirms physiologic validity*
- *Honest documentation protects everyone.*



CHAPTER

6

Recording Auditory Evoked Responses: Science and Art

Recording auditory evoked responses is not a button you press.

It is a balance.

A balance between science and judgment.

Between protocol and intuition.

Between precision and patience.

The science tells you how to record.

The art tells you when to stop, when to repeat, and when not to trust what you see.

The Science Behind Recording

At its core, recording evoked responses is governed by science.

You control:

- *Electrode placement and impedance*
- *Stimulus parameters*
- *Averaging and filtering*
- *Analysis windows*

These elements follow rules.

They are measurable, teachable, and reproducible.

Without scientific control, recording becomes noise collection.

Why Science Alone Is Not Enough

Two recordings can follow the same protocol

and still tell different stories.

Why?

Because patients move.

States change.

Noise fluctuates.

And protocols cannot anticipate every situation.

This is where art enters.

The Art of Knowing When a Response Is Real

A real response is not just visible.

*It is **repeatable**, **stable**, and **consistent** with physiology.*

The art lies in recognizing:

- *when a waveform looks good but is unreliable*
- *when a weak response is actually meaningful*
- *when repeating the test adds value*
- *when stopping prevents false certainty*

These decisions are not written in manuals.

They are learned in clinics.

Patient Interaction Is Part of Recording

Recording does not begin with electrodes.

It begins with the patient.

*How the patient is positioned,
how calm the environment is,
and how stable the state remains
all affect the final result.*

*Good clinicians manage the patient
as carefully as they manage the equipment.*

Noise, Artifacts, and Judgment

Noise is inevitable.

Judgment is optional.

*Muscle activity, electrical interference, and movement
can all mimic neural responses.*

The art of recording is knowing:

- *when noise is acceptable*
- *when it invalidates interpretation*
- *and when repeating is the safest choice*



Figure 6.1. An adult prepared for auditory brainstem response (ABR) recording with insert earphones and electrodes in position. ABR measurement is described in the text.(Image courtesy of James W. Hall, III.)

Stimulus Parameters and Response Characteristics

Auditory evoked responses are highly dependent on the characteristics of the acoustic stimulus. Small changes in stimulus parameters can significantly alter waveform morphology, latency, and clinical interpretation. This chapter explains how stimulus selection shapes evoked responses and why understanding stimulus behavior is essential for accurate diagnosis.

Misinterpretation of evoked responses often results from misunderstanding stimulus effects rather than true neural abnormality. This chapter helps clinicians:

- Select appropriate stimuli for specific clinical questions*
- Predict how waveform characteristics will change with stimulus manipulation*
- Avoid diagnostic errors caused by inappropriate stimulus settings*

Stimulus control is a core component of evidence based evoked response testing.

Fundamental Stimulus Parameters

Stimulus Intensity

Stimulus intensity directly influences evoked response visibility and timing. As intensity increases:

- Waveform amplitudes increase*
- Latencies decrease*
- Neural synchrony improves*

Near threshold levels, responses become smaller and less distinct, requiring careful replication and interpretation.

Stimulus Rate

Stimulus rate refers to how frequently stimuli are presented.

Increasing stimulus rate results in:

- *Prolonged latencies*
- *Reduced amplitudes*
- *Increased neural adaptation*

High stimulus rates are useful for stressing the auditory system and may reveal subtle neural dysfunction, but they also reduce waveform clarity.

Stimulus Polarity

Stimulus polarity determines the initial direction of transducer diaphragm movement. Common polarity options include:

- *Rarefaction*
- *Condensation*
- *Alternating polarity*

Polarity effects are particularly important when evaluating cochlear microphonics and differentiating neural responses from stimulus artifact.

Stimulus Type

Different stimulus types emphasize different cochlear regions and neural response patterns.

Click Stimuli

Click stimuli are broadband and activate a wide region of the cochlea, with greatest contribution from the basal high frequency region.

Clicks are:

- *Highly effective for generating robust responses*
- *Well suited for neural integrity assessment*
- *Limited in frequency specificity*

Tone Burst Stimuli

Tone burst stimuli provide greater frequency specificity by targeting narrower cochlear regions. They are essential for:

- *Threshold estimation*
- *Frequency specific diagnosis*
- *Pediatric and amplification related decision making*

Tone burst responses typically have longer latencies and smaller amplitudes compared with click responses.

Click vs. Tone Burst

- *In order to obtain a significant response, the stimulus should be abruptly increased to its full strength.*
- *Fast onset stimuli contains transient acoustic energy at various frequencies which diminishes its frequency specificity.*
- *The amplitude of the stimulus should be gradually increased with a sufficiently long time to obtain frequency specific information*

Temporal Characteristics of Evoked Responses

Latency

Latency reflects the time between stimulus onset and neural response.

Latency is influenced by:

- *Stimulus intensity*
- *Stimulus type*
- *Stimulus rate*
- *Auditory system integrity*

Latency changes follow predictable physiologic patterns that support clinical interpretation.

Amplitude

Amplitude reflects the magnitude of the recorded neural response.

Unlike latency, amplitude is:

- *More variable across individuals*
- *Highly sensitive to recording conditions*
- *Less reliable as a primary diagnostic marker*

Amplitude should be interpreted cautiously and in conjunction with other waveform features.

Waveform Morphology

Waveform morphology refers to the overall shape and definition of evoked response components. Morphology is influenced by:

- *Neural synchrony*
- *Stimulus characteristics*
- *Signal to noise ratio*

Consistent morphology across replications is a key indicator of physiologic validity.

Interaction Between Stimulus and Neural Function

Stimulus parameters interact with neural physiology to shape evoked responses. For example:

- *Reduced neural synchrony exaggerates rate effects*
- *Cochlear pathology alters intensity latency relationships*
- *Neural disorders may distort morphology despite adequate stimulation*

Understanding these interactions allows clinicians to differentiate technical effects from pathology.

Clinical Applications of Stimulus Manipulation

Manipulating stimulus parameters can enhance diagnostic sensitivity.

Examples include:

- *Using high stimulus rates to stress neural conduction*
- *Comparing polarity responses to identify cochlear microphonics*
- *Employing tone bursts for frequency specific assessment*

Stimulus manipulation must be purposeful and clinically justified.

Common Pitfalls

- *Using click stimuli when frequency specificity is required*
- *Overinterpreting amplitude changes*
- *Ignoring expected latency shifts with intensity or rate changes*
- *Comparing responses obtained with different stimulus parameters*

Clinical Pearls

- *Latency is more informative than amplitude*
- *Clicks assess neural integrity more than hearing thresholds*
- *Tone bursts are essential for frequency specific decisions*
- *Stimulus parameters must match the clinical question*

Standard Air Conduction ABR

Stimulus and Recording Parameters

• The nervous system (including the auditory system) is constantly active and generating electrical potentials that are conducted to the body's surface, where they can be computer- extracted and recorded with electrodes (following the presentation of a stimulus e.g. acoustic stimuli).

Basic ABR Measures

1- Morphology of the waveform.

2- ABR Latencies.

3- ABR Amplitude

How to optimize ABR recording

Optimum stimulus and recording parameters

Optimum Signal processing

Additional noise and artifact rejection strategies

Examiner, instrumental and environmental variables

How to record an ABR auditory potentials

ABR stimulus parameters

1 - Intensity

2- Stimulus type

3 -Transducer type

4 - Repetition rate RR

5 - Sweep number

6 - Stimulus polarity

7- Masking

1 - Intensity

Intensity: usually start at 70 dBnHL for threshold determination and mostly at 90 dBnHL in neuro-otologic examination.

The latencies increase as stimulus intensity decreases

- The amplitudes of the waves decrease as the intensity decreases*
- As intensity decreases the waves prior to Wave V diminish whereas Wave V often remains visible down to levels approximating the behavioral thresholds for the same stimulus.*

latency intensity function: *It is the amount of change in latency per dB change of intensity measured in micro-sec / dB.*

2- Stimulus type

- Click, frequency specific e.g. tone burst, or electric in EABR*
- The more the precise stimulus, temporally, the better synchronized the neural discharges elicited and more robust the evoked potentials.*
- The BBC brief duration minimizes stimulus artifact while providing spectrum stimulus.*

3- Transducer type

Insert, sound field, headphones, bone vibrator (for bone conduction ABR) and needle electrode placed on the promontory or electrodes of CI device in Electric ABR.

4- Repetition Repetition rate (RR)

- The repetition rate is another important parameter (must be slower enough to avoid neural adaptation but high enough for efficient data collection particularly important in testing newborn/infants.*
- 21.1 (for threshold determination), but for neuro-otologic*

examination we may need higher RR (50-70 p/second).

- The precise rate should be chosen so as not to be an integer submultiples of 60 Hz to avoid synchronizing the response sampling to this source of interference.

5- Sweep number:

1000 for threshold and may be 2000 for neuro-otologic.

6- Stimulus polarity:

rarefaction or alternating (to differentiate wave I from Ecoch-G).

7- Masking

ABR recording parameters

Electrode montage

Electrode Impedance

Filter settings

Time window

Electrode montage:

most performed with a vertical montage (high forehead [active or positive], earlobes or mastoids [reference right & left or negative], low forehead [ground])

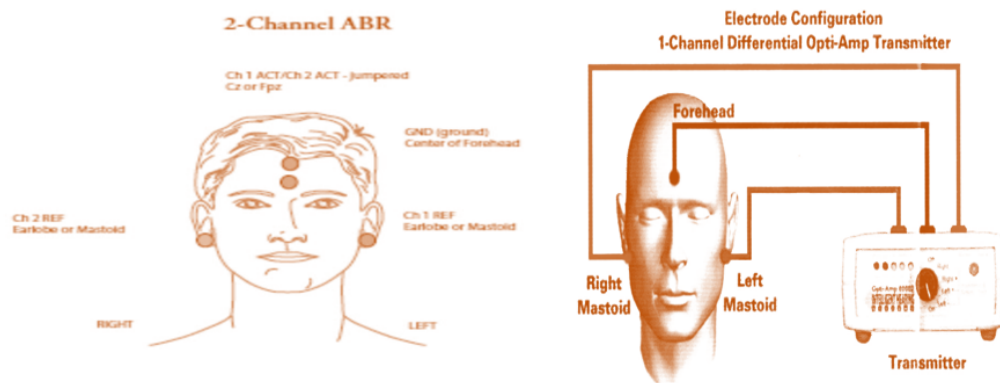


Figure 6.2. Electrode montage

Electrode montage and the deferential amplification of the signal

Deferential recording (using the deferential amplifier) amplifies the difference in voltage sampled by its two inputs the negative and the positive points.

Unwanted signals or noise common to the two inputs (A noise) are seen in the same phase and will tend to be cancelled by the amplifier. The signal or the response of interest (A signal), is seen in opposite phase by the two electrodes and thus will be enhanced via differential amplification.

Bioelectric signal conditioning

Amplification:

The purpose of amplification is two fold:

- 1 -Magnify the recorded signal to bring it within the range of amplitude resolution of the analog-to-digital converter.*
 - 2 -To optimize the voltage sampling for the desired potential while, as much as possible, rejecting unwanted signals (deferential recording).*
- The gain of the amplification depends upon the AEP recorded and the location of the electros (far-field or near field), for ABR 100,000 to 500,000.*

Electrode Impedance

The skin is electrically insulative, particularly the corneum stratum (opposes current flow because of difference between bioelectrically and physical electricity (there can be no net change transfer).

Electrode impedance should be measured routinely and as a rule, should not exceeds 5 kohms.

Inter-electrode impedance should be balanced to optimized common-mode rejection (should not exceed 2 kohms).

Factors affecting impedance measurement

- Electrode material: Silver, Gold and Platinum have relatively low impedance in this application.*
- Surface area and the tissue to which it is interfaced and anything in between (Impedance is also lowest when electrode makes direct contact with body fluids).*
- Good electrical contact for surface electrodes (good cleaning and applying an electrolyte gel o cream).*

Filter settings

(300–3000 Hz bandwidth)

Filtering: *considerable background noise actually can be removed via filtering since the noise generally has a much broader spectrum signal.*

-High-pass filtering *is used to eliminate very low- frequency and direct current potentials.*

-Low-pass filtering *is used to reject noises beyond the sampling limits of A-D converter process plus high frequency noise.*

-Time window: *15ms (A longer epoch of 20 or 25 milliseconds is recommended when testing infants or any patient that may have neurological issues).*

Monaural Versus Binaural Stimulation

(Binaural interaction component of ABR)

- *Binaurally stimulated brainstem responses are larger than monaurally elicited responses by almost twofold (Dobie & Norton, 1980).*
- *Binaural stimulation can be used for screenings (the peripheral auditory mechanism is intact in at least one ear)*

*Binaural interaction in ABR recordings has been the subject of extensive experimental investigation. Despite this large body of research, **binaural stimulation is rarely used in routine clinical ABR practice**. Accordingly, discussion of binaural ABR is brief and deliberately cautious, consistent with evidence-based clinical priorities .*

Interest in binaural interaction stems from the fundamental role of binaural hearing in auditory perception, particularly:

- *Sound localization*
- *Binaural fusion*
- *Processing of interaural time differences*
- *Processing of interaural intensity differences*

*Another motivating factor is the anatomic localization of binaural processing within the **caudal brainstem**, especially the superior olivary complex, raising the possibility of objectively probing these structures using ABR or related responses such as the frequency-following response (FFR) .*

Terminology

Several terms appear in the literature to describe differences between monaural and binaural ABRs, including:

- *Binaural interaction*
- *Binaural summation*
- *Enhancement*
- *Augmentation*
- *Advantage*
- *Binaural difference wave*

The term **binaural interaction**, quantified as the **binaural interaction component (BIC)**, is preferred because it does not imply a simple increase in amplitude and allows for complex interaction effects .

Characteristics of the ABR With Binaural Stimulation

Early studies reported enhancement of ABR wave amplitudes, particularly wave V, during binaural stimulation compared to monaural stimulation. In normal subjects, wave V amplitude with binaural stimulation has been reported to be **30 percent to 200 percent greater** than with monaural stimulation, yielding a binaural-to-maural amplitude ratio of approximately **1.5 to 2.0** .

However, findings are **highly variable**:

- *Some studies show no significant amplitude enhancement*
- *Others report smaller wave V amplitude or shorter latency with binaural stimulation*
- *Inter-subject variability is substantial*

Thus, enhancement is not a reliable or consistent finding.

The Binaural Difference Wave

A common analytic approach is to:

1. *Record monaural ABRs from each ear*

2. Digitally sum the monaural waveforms

3. Compare this summed waveform with the actual binaural ABR

If binaural interaction exists, the actual binaural response should differ from the summed monaural response. Subtracting the two produces a **binaural difference (BD) waveform**, attributed to binaural interaction .

Characteristics of the BD Waveform

- Appears primarily in the **wave V time region**
- Typically consists of two positive and two negative peaks
- Peak latency usually slightly later than wave V
- Amplitude is extremely small, usually **10 to 20 percent of wave V amplitude**
- No binaural interaction is observed for waves I, II, or III

Importantly, the subtraction process itself introduces noise and degrades the signal-to-noise ratio, complicating reliable detection of the BIC.

Physiological Basis of Binaural Interaction

Animal studies clearly demonstrate binaural processing within the auditory brainstem. Structures implicated include:

- Medial nucleus of the trapezoid body
- Medial superior olive
- Lateral superior olive
- Inferior colliculus

Despite extensive investigation, **no consensus exists** regarding the precise anatomic generators of the ABR binaural interaction

component in humans. Lesion studies and animal models support brainstem involvement, but translation to clinical ABR interpretation remains uncertain .

Clinical Limitations

Several factors severely limit the clinical usefulness of binaural ABR:

- *Extremely small amplitude of the BIC*
- *Poor reliability even in normal-hearing subjects*
- *Frequent absence of BIC in mild peripheral hearing loss*
- *Strong dependence on stimulus parameters, acquisition settings, and subject variables*
- *Sensitivity to interaural asymmetries, crossover, and middle ear effects*

As a result, binaural interaction ABR **does not provide robust, reproducible clinical information** suitable for routine diagnostic use.

Clinical Summary on Binaural Stimulation

Binaural interaction can be demonstrated experimentally under controlled conditions, but its **clinical value remains unproven**. The complexity of measurement, small signal amplitude, and susceptibility to confounding variables severely limit its diagnostic applicability. Consequently, monaural stimulation remains the clinical standard for ABR assessment.

Concluding Comments on Stimulus Parameters

Selection of stimulus parameters is one of the most critical determinants of ABR quality and diagnostic accuracy. Stimulus parameters directly influence:

- *Waveform morphology*
- *Latency values*
- *Signal-to-noise ratio*
- *Test efficiency*
- *Validity of threshold estimation*

Evidence-based selection of stimulus parameters:

- *Improves waveform clarity*
- *Reduces test time*
- *Enhances diagnostic confidence*
- *Minimizes need for repeat testing*

Cautious and informed manipulation of stimulus parameters, guided by research evidence and clinical experience, often makes the difference between:

- *Poor-quality, uninterpretable ABRs*
and
- *Stable, repeatable, diagnostically meaningful waveforms*

*Optimal ABR practice is not achieved by rigid adherence to default settings, but by **deliberate, informed parameter selection tailored to the clinical objective and patient population** .*

Signal processing

- *The SNR can be improved via computer- based time ensemble averaging, this is accomplished through A-D conversion.*
- *The sampling rate of the A-D conversion process thus determines the temporal resolution of the wave form (the number of data points per cycle).*

- *Amplification must be done prior to signal averaging.*
- *The improvement in SNR is proportional to the square root of number of samples that averaged .*
- *Currently available instruments utilize a combination of analog (pre) filtering, smoothing, and digital (post hoc) filtering at the amplifier stage with, at least, low-pass digital filtering available to effect smoothing of the waveform.*

Additional noise and artifact rejection strategies

Noise sources

Electro-myogenic artifact

Amplitude artifact rejection:

Automatic rejection of the large electro-myogenic artifact (exceeding the permissible amplitude limits).

Electrostatic and electromagnetic

(specially fluorescent) lights and other electric devices and wiring that produce 60 Hz noise.

Reduced by the signal averaging process

Stimulus artifact radiation from headphone

Electromagnetic shielding the earphone, use insert phone (cause acoustic delay that helps to separate stimulus artifact from onset of response), lastly the alternating stimulus polarity (via phase cancellation).

Electrostatic and electromagnetic noise sources

Proper shielding of equipment, proper grounding and ensuing proper electrical safety for patient and examiner.

Stimulus Calibration

- *The intensity of the click stimulus frequently is reported in terms of dB above the behavioral threshold of a group of normal listeners and referred to as nHL.*
- *Currently, there is no hearing level standards of BBC and other transients.*
- *Existing audiometric calibration procedures are not available (sound level meter require long duration signals).*
- *Determination of peak-equivalent sound pressure level (peSPL) by oscilloscope to match the amplitude of a sine wave with the peak amplitude of the click stimulus. The SPL of the long duration pure tone can be then be measured on sound level meter (peSPL) of the click.*
- *The behavioral threshold of the BBC for normal listeners has been found to be approximately 30 dB peSPL.*
- *When determining hearing levels, the psychophysical method for threshold measurement and number and rate of stimulus presentation are important factors.*

– Clinical Summary

*The core message of this section is that while Auditory Evoked Responses (AERs) are physiologically "objective," the process of recording and interpreting them is a sophisticated blend of **science and clinical art**. Relying solely on automated protocols can lead to diagnostic errors and clinical inefficiency.*

1. The Myth of "Pure Objectivity"

AERs are often called objective because they do not require a behavioral response from the patient. However, this terminology can be misleading for two reasons:

Protocol Flexibility: A "one-size-fits-all" test protocol rarely works. A clinician must tailor the stimulus and acquisition settings to the individual patient's age, health status, and the specific diagnostic question being asked.

Interpretation: Even with high-quality data, identifying wave components and judging the reliability of a recording requires human expertise.

2. Thinking on Your Feet

Success in AER assessment depends on the clinician's ability to adapt to **unpredictable variables** in real-time. This "clinical art" involves:

Environmental Management: Adjusting settings to counteract electrical interference in a noisy NICU or Operating Room.

Subject Variables: Modifying the approach if a patient is restless, has a high body temperature, or is under the influence of certain medications.

Ongoing Analysis: Evaluating data as it is collected to determine if a waveform is a true neural response or merely residual noise.

3. Automation vs. Clinical Judgment

Automation has made significant strides, particularly in specific areas:

Newborn Screening: Automated ABR (AABR) allows for rapid "Pass/Refer" results in healthy infants.

Neuro-monitoring: Systems can track trends during surgery to alert the team of sudden changes.

ASSR: Automated threshold estimation is increasingly common.

Despite these advances, **diagnostic clinical applications** still require an experienced clinician. A computer can identify a peak, but it cannot yet integrate that peak into the broader context of a patient's medical history, previous audiometric findings, and the subtle "morphology" (shape) of the waves.

4. The Risks of Oversimplification

The text warns that viewing AERs as simple "cookbook" tests is dangerous. It can lead to:

False Security: Overconfidence in a technician's ability to run a test without understanding the underlying neurophysiology.

Inaccuracy: Failing to recognize when a recording is invalid due to artifact or poor electrode placement.

Inefficiency: Sticking to a rigid protocol when a change in strategy (like slowing the stimulus rate or changing a filter) would obtain the necessary data much faster.

Key Points

- Recording evoked responses requires both technical accuracy and clinical judgment.
- Repeatability and consistency define reliable responses.

Common Mistakes

- *Trusting appearance over repeatability.*
- *Rushing recording due to time pressure.*
- *Ignoring patient-related noise.*

Red Flags

- *Responses that disappear on repetition.*
- *Conclusions made from single, unverified traces.*

Pitfalls

- *Confusing artifacts with neural responses*
- *Stopping early to save time*

Ethics

- *Patient outcomes depend on recording honesty.*

Documentation

- *Document repeatability and noise levels.*
- *Note patient state and cooperation.*
- *Record any deviations from standard conditions.*

Report Writing

- *Avoid confident language when recording quality is borderline.*

Take-Home Messages

- *Good recording is both technical and clinical.*
- *Repeatability defines reliability.*
- *Honest recording supports safe decisions.*

If you hesitate to repeat the recording, you should hesitate to interpret it.



CHAPTER

7

Maturation of the Auditory System
ABR Findings in Infants & Neonates

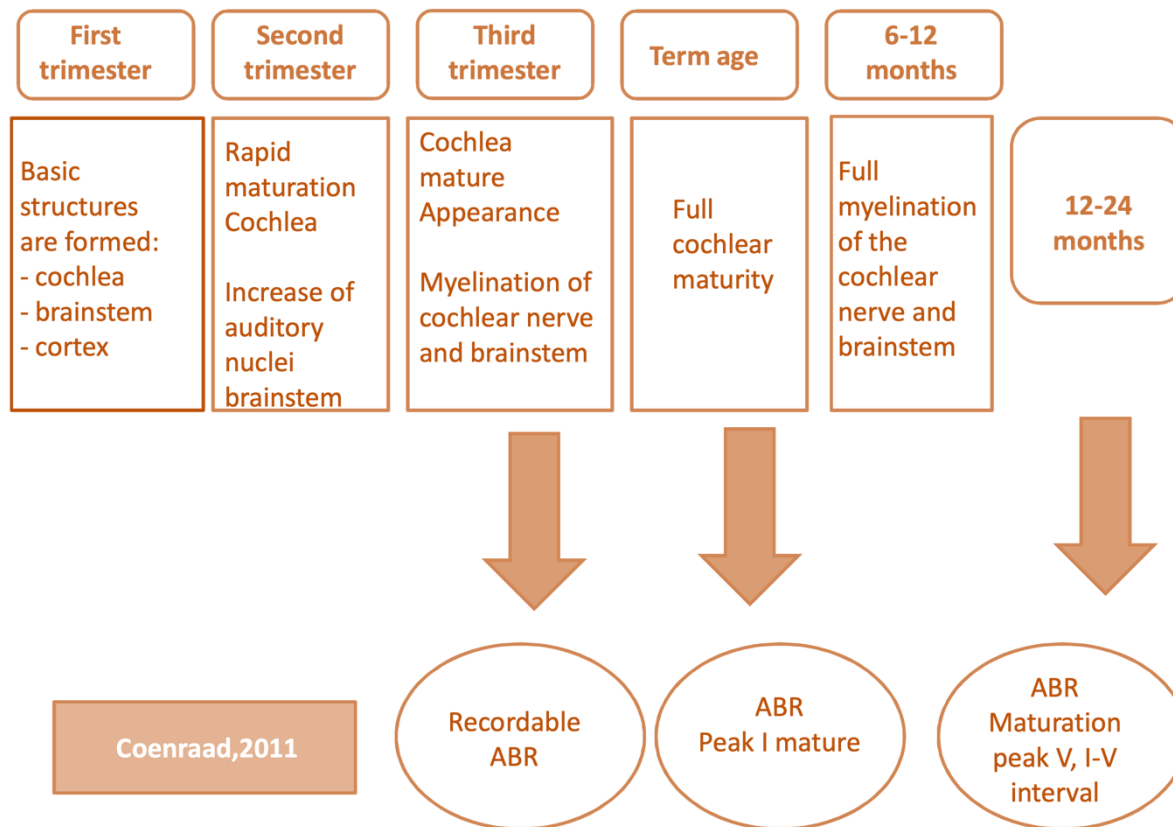


Anatomically

- *Fetus' hearing starts to develop on the 22nd day of gestation and the inner ear matures structurally during the fifth month intrauterine.*
- *The sensory and brain mechanisms for hearing are intact at 30 weeks of gestational age.*
- *The ABR response in human development first appears around 25 weeks gestational age.*
- *This response matures during the first one and half years of life.*

In Full Term Infants

- *The peripheral response, reflected in peak I, is reported to show full maturation.*
- *Auditory neurons reach about 50-60% of their adult size at birth.*
- *The central conduction time, reflected by I-V interval, is reported to mature until 11 to 18 months.*



Flowchart 7.1: Maturation of the Auditory System

Objectives of ABR Testing in Infants & Neonates

Screening

Diagnostic Procedures

Studying Delayed Maturation

Diagnosis of Auditory Neuropathy Spectrum Disorder (ANSD)

Adults vs. Infants & Neonatal ABR

A general pattern of maturation, characterized by a decrease in ABR wave latencies and an increase mean sensitivity is observed with age.

- ☐ More clear morphology
- ☐ Decrease in absolute latency
- ☐ Decrease in inter peak latency
- ☐ Better threshold

Infant ABR

- *To adequately diagnose hearing loss, age adjusted normal values are required.*
- *Several authors have reported average ABR normal values for infants of specific ages.*
- *Postconceptional age is the main concern when delayed auditory maturation is diagnosed.*
- *This maturation effect differs for preterm and term infants.*
- *Preterm infants are reported to have increased latencies compared to term infants up to two years of age.*
- *They may also display elevated ABR thresholds in the presence of normal peripheral hearing.*

Age-dependent changes of ABR latencies in normal hearing infants.

N= 175 normal hearing infant

Coenraad et al,2011

Peak I latency shows little or no age-dependency.
Peak III and V latencies show a clear age-dependent decline.

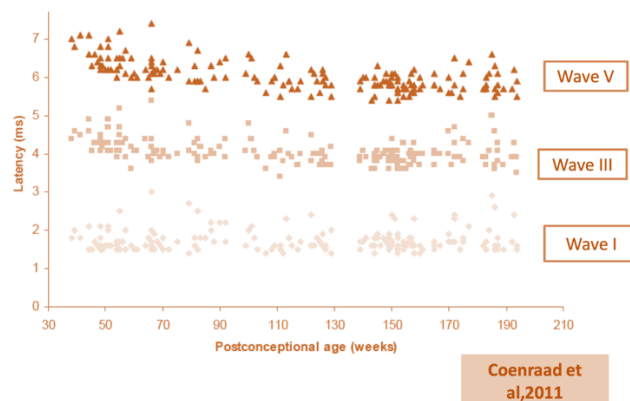


Figure 7.1. Maturation of the Auditory System

Signs of delayed auditory maturation in ABR

Persistence of ABR pattern which is not consistent with PCA age in terms of :

- *Waveform morphology*
- *Absolute latency*
- *Inter-peak latency*
- *Elevated ABR threshold out of proportion to other audiological test battery.*

Protocols for Diagnostic Audiological Assessment

“Position Statement“2013”

General rules

- *Screening at no later than 1 month of age.*
- *Comprehensive audiological evaluation at no later than 3 months of age for failed screening.*
- *Appropriate intervention at no later than 6 months of age.*
- *Follow up for hearing by H.As at : 9 and 12 to consider C.I.*

Diagnostic Protocols

“International consensus based on JCIH 2007”

The click air conduction ABR can miss both low and high frequency hearing loss.

500,1000,2000,4000 Hz AC tone bursts should be used (different protocols) + Clicks +/- Chirp.

BC testing is also included when feasible.

Diagnostic Protocols Stimulus & Recording parameters

- *Montage : Fz,M1,M2*

- *Receiver* :Insert / headphones
- *Stimulus* :click, 500, 1000, 2000, 4000 Hz.TB
- *Filters* : 30Hz - 1500Hz
- *Window* :20 ms -25ms
- *Number of sweeps*: 2000 (minimum: 1500)
- *Polarity* :alternating
- *Calibration values for dBnHL, SPL and eHL*

Relation between ABR threshold and Audiometric threshold

- *dB SPL*
- *dB nHL* :
- *eHL* : Estimated “Behavioural” Hearing Threshold

Correction of nHL threshold to eHL in infants (DSL m[i/o] v5.0)

	500 Hz	1000 Hz	2000 Hz	4000 Hz
dB nHL	50	60	65	65
Correction (dB)*	- 20	- 15	- 10	- 5
dB eHL	30	45	55	60

Table 7.1. Correction of nHL threshold to eHL in infants

1) Visual interpretation :

- *CR*: Clear Response present
- *RA*: Response Absent
- *Inc*: Inconclusive

2) Objective measures for ABR interpretation :

These method compares the variance of the averaged ABR waveform to the variance of the background noise level.

Take Home Messages

1-When Infants Hearing is Concerned

- *The challenge is to be able to determine in which infants hearing function is truly impaired and in which infants hearing function will improve as a result of auditory maturation.*
- *A combination of postconceptional age, I-V interval and ABR threshold will provide a reasonable approach.*

2-In Preterm Infants

- *The auditory system is still in full maturational process.*
- *This makes adequately diagnosing hearing loss a challenge.*
- *The ABR morphology is immature and sometimes poorly detectable in NICU graduates.*
- *Frequent repetition of ABR measurements is essential to monitor possible maturation effects.*

3- Parents Counselling

- *Careful counselling strategies are required when hearing loss is presumed, since that the audiologic diagnosis may well change over time.*



CHAPTER

8

Auditory Evoked Response Measurement in the Real World

Textbooks describe ideal conditions.

Clinics rarely offer them.

In the real world, patients move.

Time is limited.

Noise exists.

Pressure is constant.

And yet, decisions must still be made.

*This chapter is about what happens **outside the textbook**—
where evoked responses are measured in imperfect conditions
by clinicians who must still protect patients.*

The Reality Gap

Between theory and practice, there is a gap.

Protocols assume:

- *quiet rooms*
- *stable patients*
- *unlimited time*

Real clinics offer:

- *crying infants*
- *busy schedules*
- *electrical noise*
- *urgent referrals*

Understanding this gap is not an excuse.

It is a responsibility.

Working with Imperfect Patients

In real life, patients are not optimized for testing.

Infants wake up.

Children move.

Adults tense muscles.

Real-world measurement requires:

- *flexibility without compromising standards*
- *knowing when to pause, repeat, or stop*
- *recognizing when data quality is insufficient*

Good clinicians do not force results.

*They **respect limitations**.*

Time Pressure and Clinical Judgment

Time pressure is one of the most factors.

Rushed recordings look efficient.

But efficiency without reliability creates risk.

In the real world, judgment means deciding:

- *what is “good enough”*
- *what must be repeated*

- *what should not be interpreted*

Speed is never a justification for false certainty.

Noise Is Not the Enemy—Misinterpretation Is

Noise is inevitable.

Misinterpretation is optional.

Real-world measurement demands:

- *recognizing artifacts*
- *understanding noise patterns*
- *knowing when filters help—and when they lie*

*Clinicians must distinguish between
imperfect data and unusable data.*

Adapting Without Cheating

Adaptation is not manipulation.

*Adjusting stimulus rate, changing electrode placement,
or rescheduling a test
is not failure.*

It is clinical maturity.

*The real danger lies in forcing conclusions
from compromised recordings.*

The Clinician as the Final Filter

Machines detect signals.

Clinicians decide meaning.

In the real world, no algorithm replaces:

- *experience*
- *caution*

- *ethical restraint*

The clinician remains the final filter between data and decision.

Most errors in evoked testing

do not occur because clinicians lack knowledge.

They occur because real-world pressures

push interpretation beyond safe limits.

This chapter exists to slow that moment down.

- *Ideally, an audiologist should first develop a firm grasp of the principles underlying auditory evoked responses measurement and analysis.*
- *Clinician then needs to record responses from dozens of normal persons under optimal measurement conditions to develop necessary technical and clinical skills.*

(James Hall, 2015)

Please know that.....

There are myriad interactions among the effects of subject characteristics, stimulus & acquisition parameters, auditory pathway & other factors on AEPs.

Accordingly,.....

- *Set your classic protocol*
- *Modify according to your needs*

Stimulus Parameters

Defined according to aim of testing

Transient (ABR)

EPs that occur following a change in the stimulus, e.g. onset, offset.

Sustained (ECochG SP)

Responses that are evoked continuously throughout the stimulus

Steady-State (ASSR)

If the stimulus is changing regularly

CE Chirp



Figure 8.1 .(Images courtesy of James W. Hall, III.)

ABR Click vs. CE-Chirp for Threshold Estimation

- Both are broad band stimuli (not frequency specific)
- The response is more robust upon using the chirp
- Chirp wave V is as double as the amplitude of click evoked V and shorter latency

- *Less averaging is needed*
- *Reduction of the test time into half*

Clinical value of CE-Chirp for Threshold Estimation

- *Neonatal hearing screening*
- *NICU*
- *Infants and children*

Stimulus Polarity and Activation of the Auditory Brainstem Response (ABR)

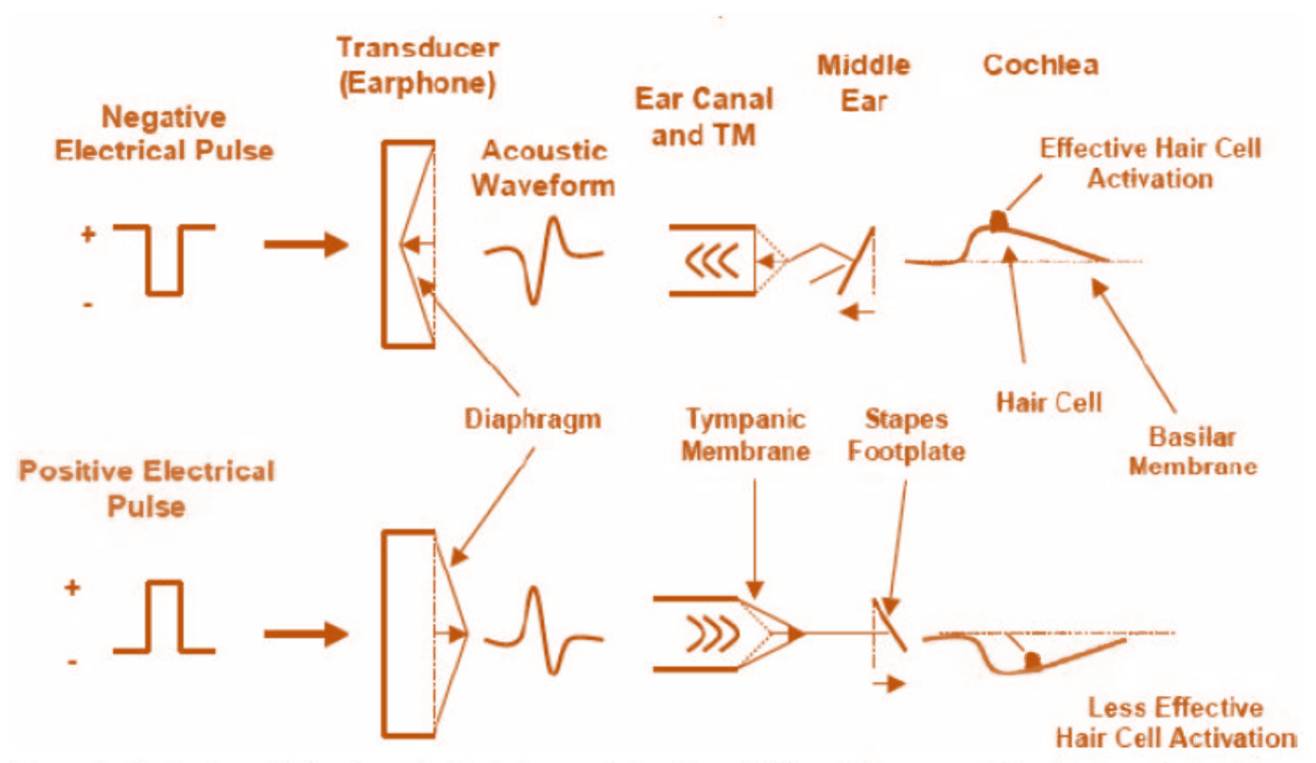


Figure 8.3. (Image courtesy of James W. Hall, III.)

Stimulus type: Modification – C-ABR

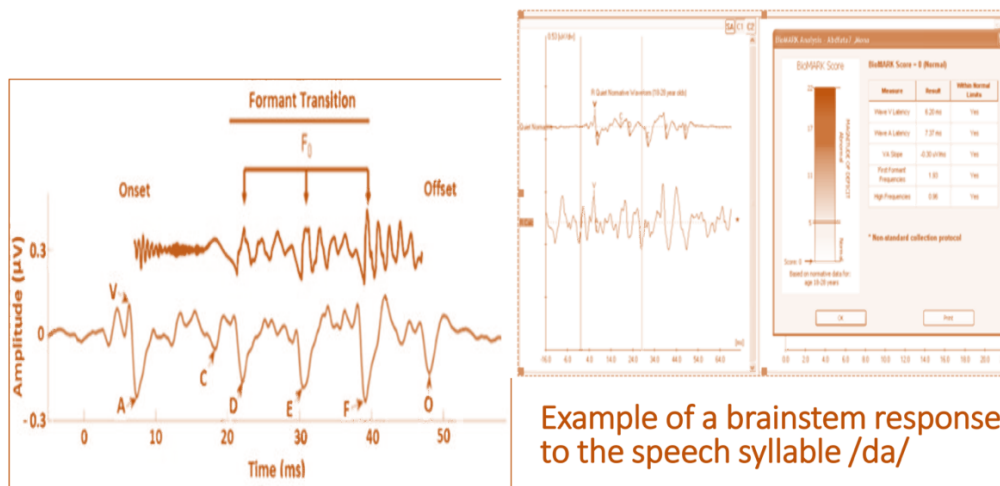


Figure 8.4. (Image courtesy of James W. Hall, III.)

Stimulus type: Modification – E-ABR

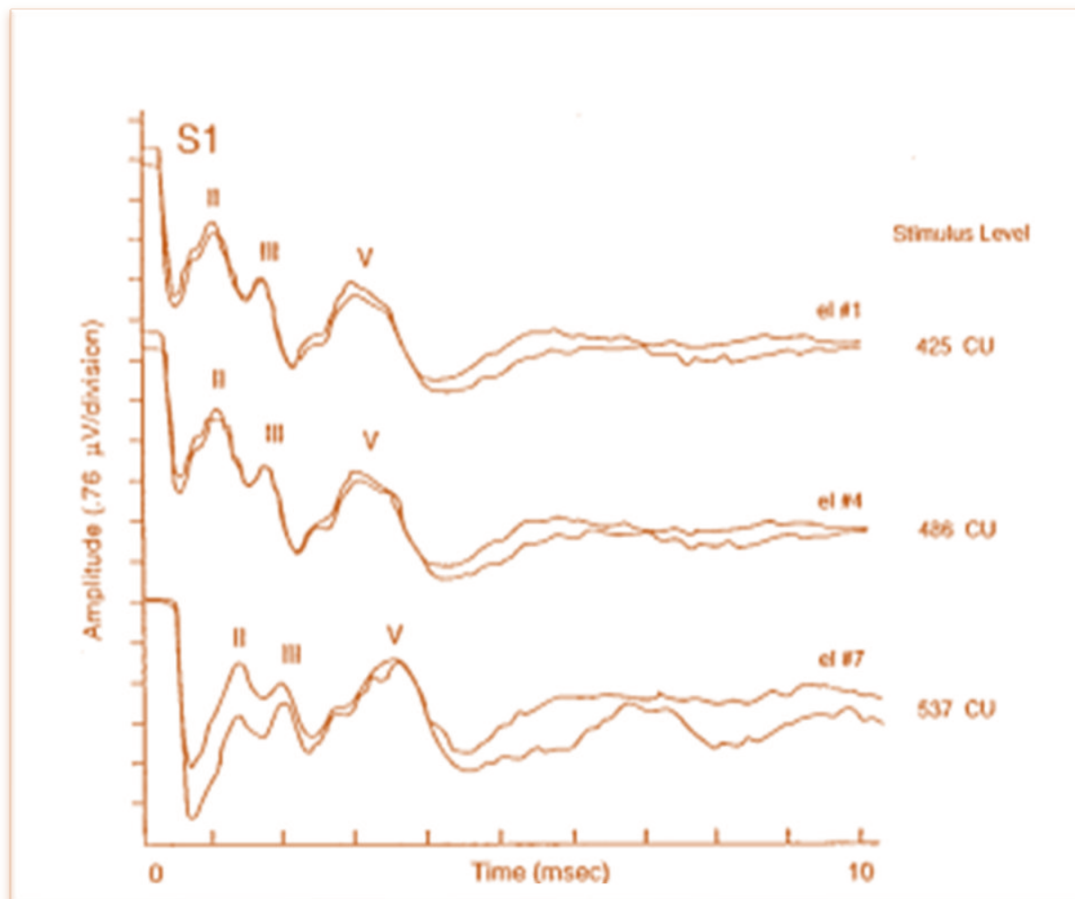


Figure 8.4. (Image courtesy of James W. Hall, III.)

Transducers: Classic vs modifications

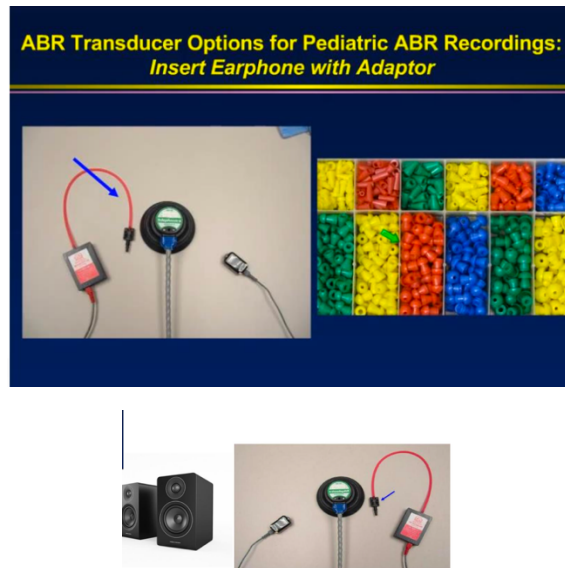


Figure 8.5. (Image courtesy of James W. Hall, III.)

Electrode type



Figure 8.6. (Image courtesy of James W. Hall, III.)

Successful ABR Recording

- *Knowledge (textbooks & internet courses)*
- *Set-up your EP lab & your equipment (Practicum)*
- *Set your protocol(s) to suite your population (Clinical applications)*

- Establish your normative data (Interpretation)
- Know how to modify your protocol in special situations
- Avoid pitfalls/common errors
- Collect data & analyze (Practicum)
- Consult experts

Response Parameters

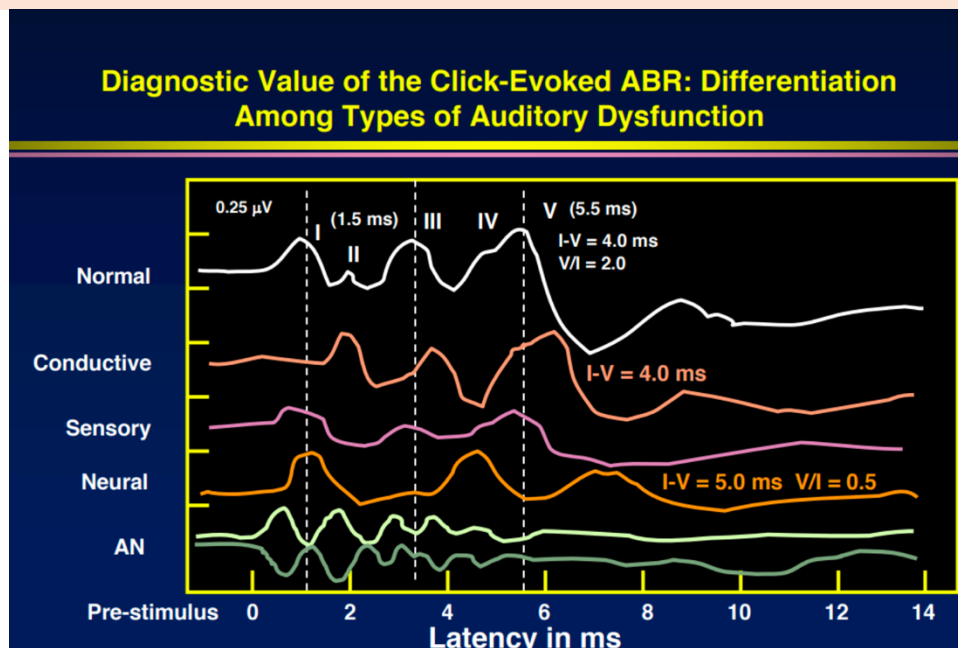


Figure 8.7. (Image courtesy of James W. Hall, III.)

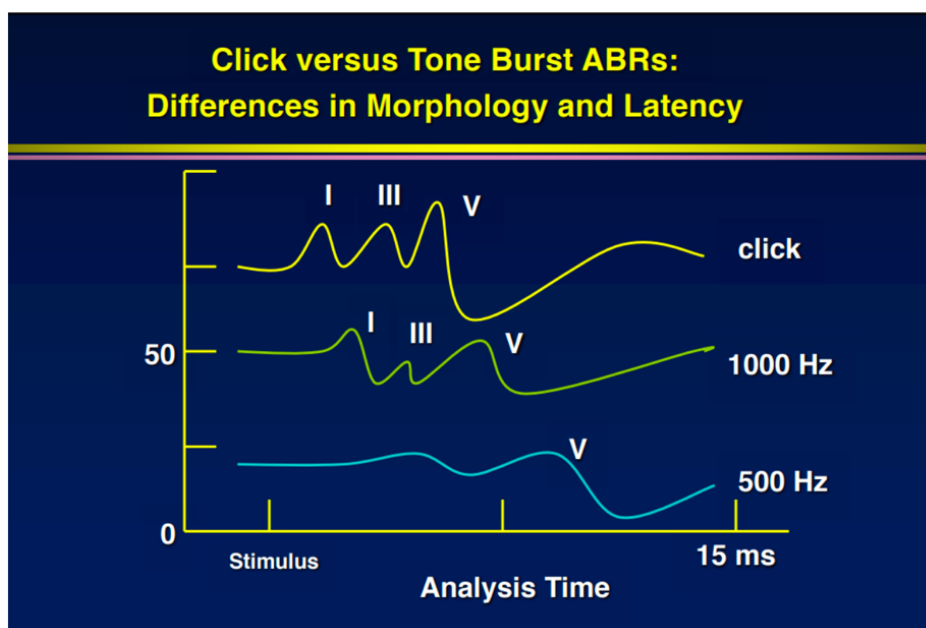


Figure 8.8. (Image courtesy of James W. Hall, III.)

Clinical Applications of ABR

I- Diagnostic:

Threshold Determination

Detection of site of lesion

Diagnosis of Endolymphatic Hydrops CHAMP.

As a part of electrophysiologic test battery for diagnosis of central auditory processing disorders.

Neurologic diagnosis: e.g. Brain death (Absence of all waves except I and later it progresses peripherally and wave I disappears.

II- Therapeutic:

HA selection and evaluation aided vs unaided ABR.

Role of Electric ABR (EABR) in cochlear implantation

III- Monitoring:

Intra operative monitoring during CPA tumor surgery.

IV- Screening:

Newborn hearing screening

Threshold Determination

Indications:

In whom routine behavioral audiological procedures could not be done as in:

Infants & Young children

Developmentally delayed children

Multiply handicapped children and adults

Difficult to test patients

Autistic individuals

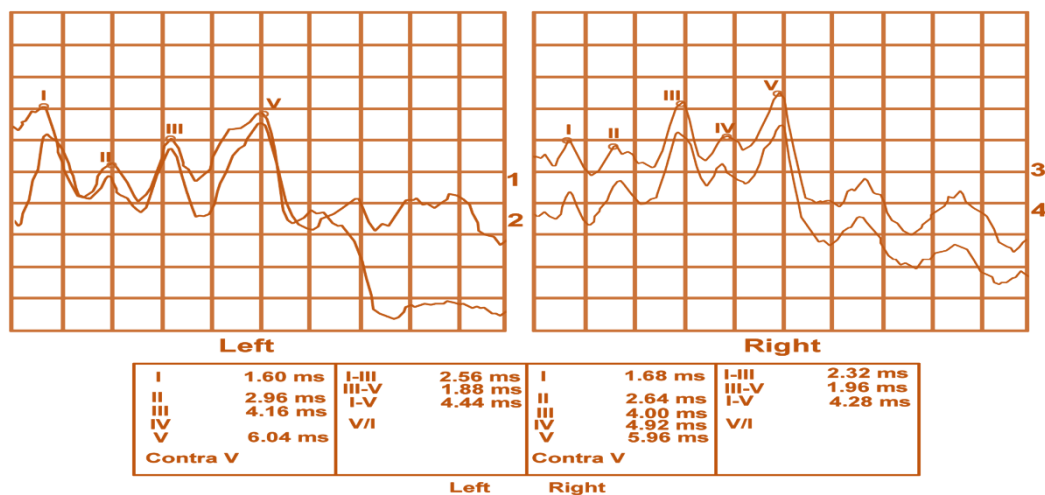
Suspected functional patients (non-organig hearing loss)

Wave V threshold

The lowest click level at which wave V can be elicited provides information about the degree of HL.

In normal and CHL, click wave V threshold is generally about 10 20 dB higher than the best audiometric threshold within the mild to high frequency range.

Normal adult ABR wave form response



Normal adult ABR waveform response. I-V absolute latencies and interpeak intervals (I-III, III-V, I-V) are within normal limits bilaterally. Interaural differences for the I-V interpeak intervals (1.16ms) and wave V absolute latencies (.08 ms) are within normal limits.

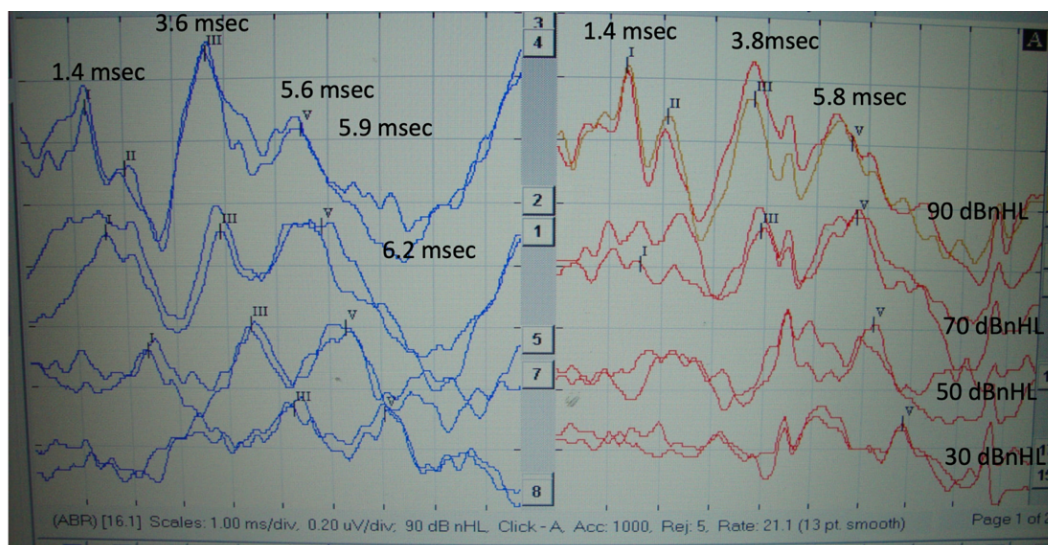


Figure 8.9. Normal ABR Trace

Detection of site of lesion

Sensorineural (cochlear) hearing loss (SNHL)

Retro-cochlear (Neural / brain stem) lesion

ANSD

ABR findings in CHL

- CHL prolongs all ABR absolute latencies in AC stimuli due to reduction of stimulus energy level.
- Wave V prolongation occur by 0.3-0.6 ms/10 dB of CHL.
- IPL:IPL: normal in CHL
- Wave V latency intensity function: Wave V latency intensity function: The slope of the LIF typically is normal. It runs parallel to the normal curve, but it is shifted to the right proportionally to the amount of HL.

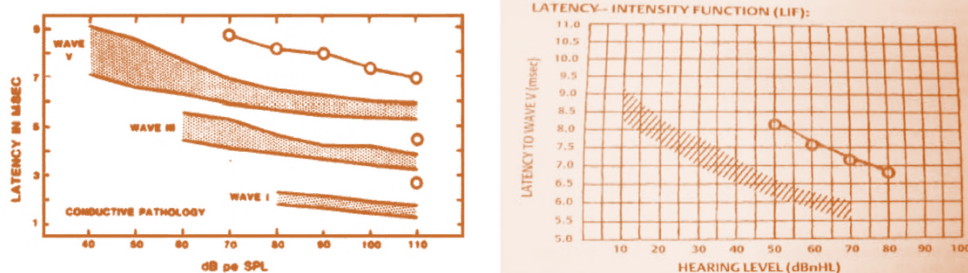


Figure 8.10. ABR findings in CHL

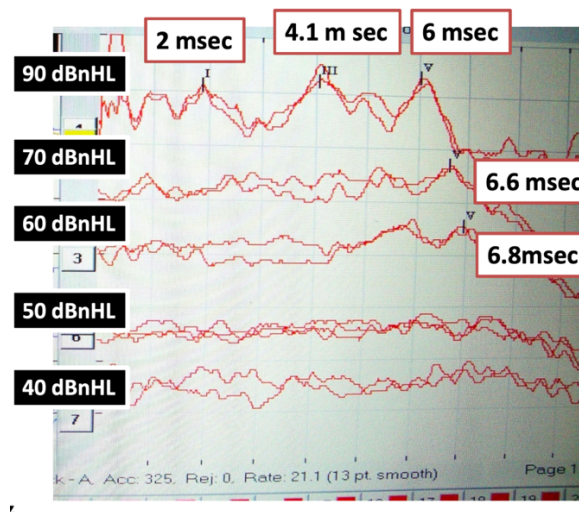


Figure 8.11. ABR findings in CHL

Bone conduction ABR

Indications:

- *To estimate the cochlear reserve in cases of congenital meatal atresia, microtia and congenital middle ear anomalies or pathology.*

Technical differences in bone conduction ABR: Technical differences in bone conduction ABR:

- *Maximum output is around 60 dB nHL.*
- *The dominant frequency is around 1500 Hz versus 3000Hz for air conduction click ABR (increased bone vibrator mass)*
- *Same morphology as air conduction ABR but the responses have longer latencies by about 0.4-0.5 ms than AC delivery at the same intensity (due to increased travel time along cochlear partitions for low frequency BC stimulus).*

Problems encountered in bone conduction ABR:

- *No calibration standard.*
- *Cross-over (IA attenuation = zero): Contralateral masking is essential in BC ABR, but in AC ABR is not necessary below 115-125 dB SPL, as cross over occurs at 70-75 dB.*
- *Middle ear artifact.*
- *Constant vibrator force*
- *Limited bone oscillator output: up to 60 dB nHL only which is around 40 dB below that of the earphones.*

Thus, the absence of a click-evoked potential by bone conduction does not necessarily imply solely sensorineural impairment; a moderate or more severe degree of mixed loss might be involved.

ABR findings in SNHL

Factors affecting ABR test results in SNHL patients:

1- Degree of SNHL:

If HL around 70dB HL, ABR response may be absent.

2- Audiometric Configuration:

-Wave V latency shows prolongation as the slop of PTA increases towards the high frequency

-For low frequency SNHL, also shows prolongation of wave V absolute latency with no effect on IPL I-V

3-Recruitment: *At high supra threshold levels, short latencies and increase in amplitude than expected. With decrease in intensity, there is rapid change in intensity latency and intensity amplitude functions.*

Wave V latency intensity function

In recruitment: much steeper due to rapid latency changes with small increments of click intensity.

ABR latencies:

If the HL is greater than 55 dB, there is prolonged latency of 0.15 msec/10 dB hearing loss.

Both age of the patient and degree of HL must be considered when measuring ABR latencies.

Latency intensity function in flat SNHL: Latency intensity function in flat SNHL:

- *Wave V latencies Wave V latencies may fall within the normal range for all latencies where*

present or may be slightly prolonged at levels near threshold. The prolongation will generally be less than seen for CHL.

- There is no definite value of latency shift that will consistently differentiate between conductive and cochlear hearing loss.

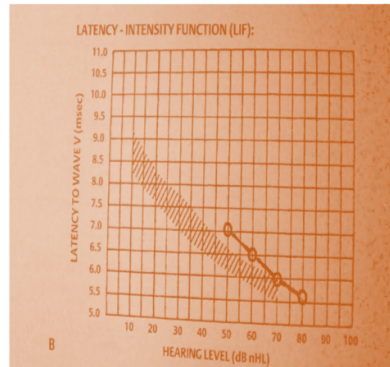


Figure 8.12. Latency intensity function

Latency intensity function in high frequency SNHL

- The slope of LIF is steeper than normal .
- A steep slope occurs when wave V latency is substantially prolonged at and near threshold but is normal or nearly normal at higher intensities.

The steep slope is felt to be related to the configuration of the pure tone audiogram. This is because wave V latency is determined in part by the region of the cochlea where the response is initiated, latency will be shorter when high frequency fibers in the basal region are stimulated and longer when lower frequency fibers towards the apical region are stimulated.

In sloping high frequency losses, the basal portion of the cochlea contributes to the ABR only at higher intensities, provided the

stimulus exceeds the threshold for high frequency fibers, whereas more apical regions contributes to the response for lower intensities.

The effect of etiology of cochlear HL on ABR

- *There are few definitive data about this relationship, as most of the disorders don't affect a particular site.*

Ex:

- *Presbycusis Cochlear and central degeneration.*
- *Retrocochlear lesion... influence cochlea (impaired blood supply).*

ABR in severe to profound hearing loss

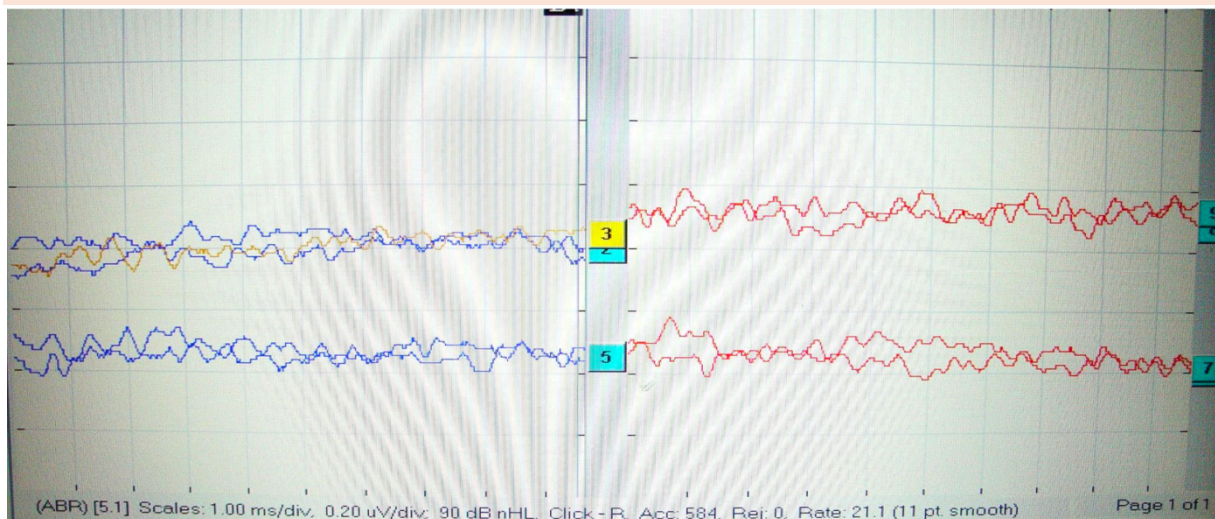


Figure 8.13. ABR in severe to profound hearing loss

Advantages & Limitations of ABR in threshold estimation

- *Objective and non-invasive.*
- *Hearing status of individual ears can be tested.*
- *Response can be recorded at low stimulus intensity levels (10-20 dB SL).*
- *There is good agreement between ABR test results and behavioral PT*

threshold specially for high frequency range (2-4 kHz).

- *Frequency specific ABR can give good idea about low frequency hearing loss and can complement click evoked ABR with other behavioral tests.*

Limitations of ABR in hearing threshold estimation (especially for click ABR)

- *Testing with click stimuli provides mostly information about the peripheral hearing status in the 2 to 4 kHz range..... So cant give information about the entire audiogram.*
- *Significant low frequency loss may go undetected (role of frequency specific ABR).*
- *It's difficult to distinguish between severe and profound hearing loss.*
- *It's difficult to distinguish between flat, falling and rising hearing loss.*
- *Normal ABR threshold does not insure normal processing of auditory stimuli at the cortical level (lower brainstem).*
- *Normal ABR does not ensure normal hearing (low frequency hearing loss, high frequency notch, ..)*
- *Time consuming, Cost effectiveness!!, not available in every clinic.*

Neurologic diagnosis

Brain death:

Absence of all waves except I and later it progresses peripherally and wave I disappears.

Prerequisites:

- The recording equipment is functioning well
- Normal hearing prior to the present disorder
- Patent EAC

II- Therapeutic:

– HA selection and evaluation (aided vs unaided ABR).

Indications:

1-Infants

2-Difficult to be examined individuals

Approaches:

Several studies have focused on three aspects or parameters of the ABR: threshold,

latency and amplitude for use in the hearing aid

selection (Davidson et al., 1990)

A- ABR threshold approach:threshold approach:

Theoretically, the hearing aid that produces the lowest (most normal) ABR threshold is the hearing aid to be selected.

B- ABR latency approach

(wave V latency and latency intensity function):

The hearing aid that produce the shortest wave V latency, also produce the best discrimination scores

(Cox and Metz, 1980)

C- ABR amplitude approach:

The use of unaided ABR projection procedure which based on normal amplitude-intensity functions to select appropriate hearing aid gain and compression.

Disadvantages

- *The click stimulus is very brief and can be significantly distorted both in the sound-field speaker and in the hearing aid (Garnham et al, 2000).*
- *Hearing aids react differently to rapidly changing stimuli, such as those used to elicit an ABR, than to more continuous stimuli which leads to distortion of the stimulus (Mahoney, 1985).*
- *The click ABR is mainly related to high frequency gain, and correlation between wave V latency and loudness is low, particularly when there is a sloping hearing loss (Picton et al, 1998).*
- *The brief stimuli that are optimal for ABR recordings may not activate the hearing instrument's compression circuitry in the same way as longer duration speech sounds (Brown et al, 1999), and may be treated as 'noise' by hearing instruments with speech detection algorithms (Alcantra et al, 2003).*
- *Lengthy test time.*
- *Lack of frequency specificity.*
- *Difficulty in precisely determining wave V latency in distorted wave forms or absent response in severe to profound hearing loss.*
- *Threshold method does not providing any indication of supra threshold function (can lead to selection of H.A. which are uncomfortably loud).*
- *Amplitude method is based on the assumption that the amplitude of the ABR is directly related to the loudness of the stimulus an*

assumption which has not been validated in normally hearing or hearing impaired listeners (Davidson et al., 1990).

For these reasons attempts to use the ABR to evaluate hearing instruments have largely been abandoned (Purdy et al, 2005).

Electric ABR and Cochlear implantation

- *It is the electrically evoked potentials arising in the first 5 msec following the stimulus.*

- *Done intra and postoperative for cochlear implant patients*

Electric vs. Acoustic ABR:

1- The stimulus is biphasic current pulses 200-400 micro-sec./phase.

2-Steeper waveform

3- Shorter latencies

4- No wave I, no change in wave V latency except at threshold

5-Narrower dynamic range

- *EABR thresholds are higher than T-level and close to C level in cochlear implant patients with better response at apical electrodes.*

- *It can give an idea about integrity of auditory pathway and possible malfunctioning electrodes.*

III- Monitoring

Role of ABR in intra-operative monitoring of auditory function during CPA tumor surgery .

Purpose:

ABR can provide early indicators of changes in neurophysiologic status of the auditory nerve and brainstem during surgery.

Indications:

Hearing should be monitored during operations that cause significant risk to the patient's hearing, for example:

- Acoustic neuroma resection
(and for post-operative follow-up).*
- Vestibular nerve section.*
- Resection of meningiomas in CPA.*
- Skull base tumors.*
- Micro vascular decompression of the cochleo-vestibular nerve.*
- Comatosed patients.*
- In fluctuating disorders as MS.*

Criteria for intra-operative ABR alteration

1- Altered: Altered: means that we view a repeatable increase in major inter wave latencies (I-III, III-V, I-V) of more than 0.5 msec.

2- Warning:

means that the interwave latencies of > 1.0 msec. or the loss of clarity and repeatability of wave V or V and III or if there is decrease of V/I ratio by more than 50%

Advantages:

ABR is a rapid electro-physiological measure of the VIII nerve and brainstem and it helps in early detection of dysfunction.

Limitations of IOM ABR:

- Electric interference.*
- Operating room is very noisy.*
- Equipment problems and maintenance of sterile field during surgery.*

– Clinical Summary

Transitioning from a controlled classroom setting to "real-world" clinical practice is one of the most significant challenges for an audiologist. While the principles of **Auditory Evoked Response (AER)** measurement remain the same, the environment often shifts from a quiet clinic to high-pressure, "hostile" settings like the NICU or the operating room.

Here is a breakdown of the complex clinical scenarios described and the challenges they present.

1. High-Pressure Clinical Scenarios

The text highlights several real-world situations where the clinician must adapt their strategy instantly:

Scenario	Primary Challenges	Diagnostic Goal
NICU Newborn	Electrical interference from incubators; ambient noise; anxious parents and doctors.	Confirm hearing status for hospital discharge.
Aural Atresia (9-month-old)	Limited time in the OR (45 mins); general anesthesia; physical ear malformations.	Determine if hearing loss is conductive (surgical) or sensory.

Scenario	Primary Challenges	Diagnostic Goal
Neuro-Diagnostic (Adult)	Muscular artifact from patient anxiety; poor waveform morphology; rule out tumors.	Identify Wave I and check Inter-aural Wave V latency.
Intra-operative (Surgery)	Excessive electrical artifact; immediate feedback required for surgical decisions.	Monitor 8th nerve and brainstem to preserve hearing.
Comatose/Trauma	Influence of hypothermia, drugs, and fractures; high stakes (brain death determination).	Determine neural integrity and potential for recovery.

Table 8.1. Correction of nHL threshold to eHL in infants

2. Common Technical & Environmental Obstacles

In these settings, the clinician cannot rely on a "fixed" protocol. They must actively troubleshoot the following:

Electrical and Myogenic Interference

Electrical Noise: In the NICU or OR, machines like incubators and ventilators create electromagnetic interference.

Myogenic (Muscle) Artifact: A child with Down syndrome or a tense adult patient creates electrical noise through movement, which can bury the tiny neural response.

Physical and Physiological Factors

Ear Malformations: Cases like aural atresia (missing ear canals) require the use of bone-conduction transducers rather than standard earphones.

Temperature and Medication: Hypothermia or drugs (like sedatives or ototoxic antibiotics) can slow down neural conduction, mimicking a pathology that isn't actually there.

3. The "Art" of Real-World Testing

Success in these environments requires two things beyond technical knowledge:

Thinking on Your Feet: The ability to change filter settings, slow down the stimulus rate, or swap electrode montages mid-test to find a usable signal.

Strategic Priority: When a patient is under anesthesia or about to wake up, the clinician must prioritize the most vital information (e.g., getting a response at a high intensity first) rather than following a standard frequency-by-frequency checklist.

Key Points

- Real-world conditions differ from textbook standards.
- Patient instability and time pressure are common.
- Clinical judgment is essential under imperfect conditions.

Golden Rules

- Never let real-world pressure justify unsafe conclusions.
- No data is better than misleading data.

Common Mistakes

- Forcing interpretation under poor conditions.

Documentation

- *Record environmental challenges.*
- *Clearly state limitations affecting reliability.*

Report Writing

- *Avoid definitive conclusions under poor conditions.*
- *Recommend repeat or follow-up testing clearly.*

Take-Home Messages

- *Real-world conditions require stronger judgment, not weaker standards.*
- *Transparency protects patients and clinicians.*

In the real world, the safest decision is sometimes to stop.



CHAPTER

9

Preparation and Precautions Before the Test

Good evoked responses do not start with electrodes.

*They start **before the test begins**.*

Most recording problems are not technical failures.

They are preparation failures.

*This chapter is about everything that happens **before** the stimulus is delivered—*

the steps that quietly determine whether your results will be reliable or misleading.

Why Preparation Matters

Evoked responses are sensitive.

Small problems before testing create big problems after.

Poor preparation leads to:

- *unstable recordings*
- *excessive noise*
- *false abnormalities*
- *unsafe conclusions*

Preparation is not routine.

*It is **risk management**.*

Patient Assessment Before Testing

Before placing electrodes, assess the patient.

Key points to consider:

- *Age and developmental level*
- *Medical history and risk factors*
- *Middle-ear status*
- *Current health and comfort*

State Control: Sleep, Calm, and Stability

Patient state directly affects recordings.

Ideal conditions include:

- *natural sleep for infants*
- *minimal movement*
- *relaxed muscles*

Testing a restless patient rarely saves time.

It usually creates repeat testing.

Environment Preparation

The room matters.

*Noise, lighting, temperature, and electrical interference
all influence data quality.*

Before testing:

- *minimize electrical noise*
- *reduce distractions*
- *ensure comfortable positioning*

A calm environment supports calm recordings.

Equipment Check

Before starting:

- *check electrode quality*
- *verify impedance*
- *confirm stimulus calibration*
- *review software settings*

Default settings are not always safe settings.

Informed Communication

Preparation includes communication.

Explain:

- *what the test involves*
- *how long it may take*
- *what the test can and cannot tell*

*Clear explanations reduce anxiety,
and calm patients record better responses.*

Precautions in Special Situations

Extra caution is required when:

- *testing very young infants*
- *working with medically complex patients*
- *testing under sedation or anesthesia*

*Preparation in these cases is part of **patient safety**, not convenience.*

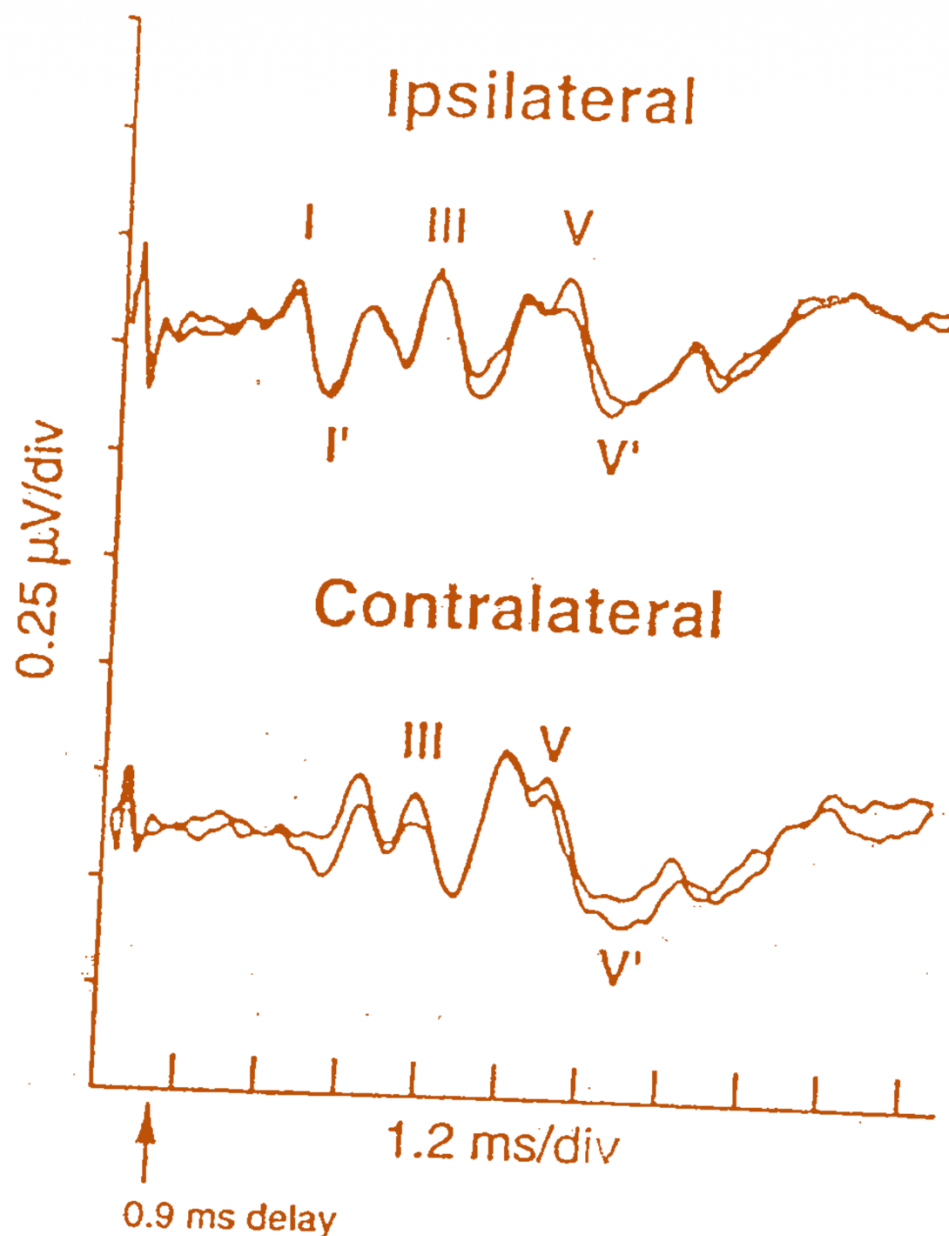


Figure 9-1. Normal ABR waveforms showing replicated ipsilateral (top) and contralateral (bottom) recordings. Waves I, III, and V are identified. The absolute latencies for the ipsilateral recording are 1.55 ms for Wave I, 3.68 ms for Wave III, and 5.63 ms for Wave V. Waveform includes a 0.9-ms delay between the stimulus and zero point for latency calculation (shown by arrow) due to insert earphones.

– Clinical Summary

Successful auditory evoked response (AER) assessment depends on meticulous preparation and empathetic communication.

This process begins long before the electrodes are applied, involving a thorough review of the patient's history, equipment checks, and clear instructions to the patient or caregiver.

1. Pre-Test Patient Review

Understanding the patient's specific needs allows the clinician to tailor the test protocol. Key clinical questions include:

- **Objective:** *Are we estimating hearing thresholds or assessing neurological status (e.g., ruling out an acoustic neuroma)?*
- **Patient History:** *What is the patient's age? Were they premature? Is there a known history of ear disease or head trauma?*
- **Existing Data:** *Are previous audiograms or behavioral test results available to serve as a baseline?*
- **Medical Factors:** *Is the patient on medications (like sedatives or ototoxic drugs) that could alter neural conduction?*

2. Equipment and Supply Management

Preparation is especially critical for mobile assessments (like in the NICU) where missing supplies can cause significant delays. The clinician must verify the following:

- **Electrodes:** *Are there enough disposable or clean reusable electrodes available?*
- **Skin Prep:** *Is there an adequate supply of abrasive liquid (to reduce impedance) and conductive paste?*
- **Transducers:** *Are insert earphone cushions available in multiple sizes (infant to adult)?*

- **Software:** Are the correct test protocols (e.g., ABR, ECochG, or ASSR) pre-loaded and ready?

3. Patient and Caregiver Instructions

Effective instructions reduce patient anxiety, which in turn reduces muscular artifact (noise) in the recording.

Overcoming the "High-Tech" Fear

The sophisticated appearance of AER equipment—computer screens, wires, and electrodes—can be intimidating. Patients often fear the electrodes will deliver an electrical shock.

- **The Reality:** Electrodes are **passive sensors** that detect natural brain activity; they do not emit electricity.
- **The "Worst" Part:** Clinicians should explain that the most "uncomfortable" part of the test is simply scrubbing the skin to ensure the electrodes stick well.

Tailoring the Message

- **For Adults:** Focus on the need to remain relaxed and still. Explain that they can sleep during the procedure, as this improves data quality.
- **For Parents:** Address concerns regarding sedation (if needed) and reassure them that the procedure is painless for their child.
- **For Specialized Cases:** Patients with communication impairments (such as those who have suffered a stroke) require extra care to ensure they understand the process.

4. Why Education Matters

A patient who understands the **What** and the **How** is a better test subject. Cooperative, relaxed patients yield:

1. **Cleaner Waveforms:** Less muscle tension means a better signal-to-noise ratio.
2. **Faster Test Times:** Reliable data can be collected with fewer stimulus repetitions.
3. **Better Clinical Outcomes:** Reduced need for rescheduling or sedation due to non-compliance.

Key Points

- Preparation determines recording quality.

Golden Rules

- **You cannot interpret your way out of poor preparation.**
- **Good preparation is the first clinical decision.**

Common Mistakes

- Ignoring middle-ear status.
- Trusting default equipment settings.

Red Flags

- High electrode impedance ignored.
- Assuming preparation wastes time!!

Ethics

- Comfort and safety come before data collection.

Final Clinical Message

Preparation is not a preliminary step.

Take-Home Messages

- *Preparation determines data quality.*
- *Poor preparation creates false problems.*

Most ‘bad recordings’ are born before the test starts.



CHAPTER

10

*Recording Auditory Evoked Responses**Stimulus Parameters*

*In evoked testing,
what you present determines what you record.
Stimulus parameters are not technical details.
They are **clinical choices**.
Change the stimulus,
and you change the response.
Understanding stimulus parameters is understanding
why a waveform looks the way it does—
and whether it deserves your trust.
Evoked responses are time-locked to sound.
The auditory system reacts differently depending on:*

- *how fast sound is presented*
- *how loud it is*
- *how brief or frequency-specific it is*
- *how polarity is delivered*

Stimulus parameters decide:

- *neural synchrony*
- *waveform morphology*
- *threshold estimation accuracy*

Using the wrong stimulus answers the wrong question—perfectly.

Stimulus Type: What Are You Asking the System?

Different stimuli ask different questions.

- ***Click:***

Asks, “Is there a synchronized neural response?”

Broad frequency emphasis, fast, robust.

- ***Tone Burst / Frequency-Specific Stimuli:***

Ask, “How does the system respond at a specific frequency?”

Slower, more selective, clinically targeted.

- ***Chirp:***

Asks, “Can we improve synchrony across the cochlea?”

Designed to align cochlear travel time.

Stimulus choice must match the clinical goal.

Stimulus Intensity: More Than Loudness

Intensity affects:

- *response presence*
- *latency*
- *amplitude*

High intensity improves visibility.

Low intensity improves threshold estimation.

*Confusing detectability with accuracy
is a common clinical error.*

Stimulus Rate: Speed Has a Cost

Faster rates:

- *reduce test time*
- *increase neural stress*
- *prolong latencies*
- *reduce amplitude*

Slower rates:

- *improve waveform clarity*
- *increase test duration*

*Rate selection is a balance
between physiology and practicality.*

Polarity: Revealing What Lies Beneath

Polarity affects how responses interact.

Alternating polarity:

- *reduces stimulus artifact*
- *may reduce cochlear microphonic visibility*

Rarefaction and condensation:

- *help identify cochlear microphonic*
- *assist in ANSD assessment*

Polarity choice can uncover—or hide—critical information.

Stimulus Duration and Envelope

Rise/fall times and plateau duration influence:

- *frequency specificity*

- *spectral splatter*
- *neural synchrony*

Shorter is not always better.

Sharper is not always cleaner.

Default Settings Are Not Neutral

Default stimulus settings are compromises—not best practice.

Using them without thought means:

- *accepting someone else's clinical assumptions*
- *risking misinterpretation*

*Stimulus parameters should be chosen,
not inherited.*

*Many interpretation errors
are stimulus errors in disguise.*

*Before questioning the auditory system,
question the stimulus.*

– Clinical Summary

*In the clinical measurement of auditory evoked responses (AERs), the selection of **stimulus parameters** is critical.*

These parameters represent the "input" delivered to the auditory system, and their characteristics directly determine which neural pathways are activated and how clear the resulting waveform will be.

1. Stimulus Type and Duration

The auditory system requires specific types of sounds to trigger synchronous neural firing.

- **Clicks:** Transient stimuli with a nearly instantaneous onset and very brief duration (0.1 ms). Clicks are the standard for **ABR** and **ECochG** because their rapid onset forces thousands of auditory neurons to fire simultaneously.
- **Tone Bursts:** Brief tonal signals (4-5 cycles). These are used to estimate hearing at specific frequencies (e.g., 500 Hz or 4000 Hz).
- **Duration Guidelines:** * **Constant Rise Time:** e.g., a 5-ms rise time for all frequencies.
 - **Constant Number of Cycles (2-1-2 Paradigm):** 2 cycles for rise, 1 for plateau, and 2 for fall. This ensures equivalent energy across different frequencies.

2. Stimulus Intensity

Intensity is measured in **decibels (dB)**. In AER measurement, intensity affects two primary components of the response:

1. **Latency:** As intensity increases, response latency **decreases** (the wave appears faster).
2. **Amplitude:** As intensity increases, response amplitude **increases** (the wave gets larger).

Intensity References:

- **dB nHL (Normal Hearing Level):** The most common clinical reference, based on the average behavioral threshold of normal-hearing young adults for that specific stimulus.

- **peSPL (Peak-Equivalent SPL):** Used to calibrate transient sounds (like clicks) that are too brief for standard sound level meters.

3. Rate of Presentation

The rate at which stimuli are presented must be matched to the response being recorded:

- **Fast Responses (ABR/ECochG):** Can tolerate faster rates (e.g., **21.1 to 27.7 per second**).
- **Slow Responses (Cortical/ALR):** Require very slow rates (e.g., **1 stimulus every few seconds**) to allow the cortex to recover.
- **Inter-Stimulus Interval (ISI):** The time between sounds. If the rate is too high, the ISI becomes too short, and the response to one sound will overlap and degrade the next.

4. Stimulus Polarity

Polarity refers to the direction of the transducer diaphragm's initial movement:

- **Rarefaction (Negative):** Diaphragm moves **away** from the eardrum. This usually produces the most robust ABR wave I and shortest latencies.
- **Condensation (Positive):** Diaphragm moves **toward** the eardrum.
- **Alternating:** The system switches between the two. This is useful for canceling out electrical artifacts or the "Cochlear Microphonic" (CM).

5. Transducers: The Role of Insert Earphones

A transducer converts electrical signals into acoustic energy. While supra-aural (over-ear) headphones and bone oscillators are available, **Insert Earphones (ER-3A)** are the clinical gold standard for AERs.

Top Advantages of Insert Earphones:

- **Artifact Reduction:** The 0.9-ms time delay introduced by the acoustic tubing separates the electrical "ringing" of the transducer from the early neural response (Wave I).
- **Infection Control:** Uses disposable foam tips.
- **Comfort:** More tolerable for infants and adults during long tests.
- **No Collapsed Canals:** Prevents the ear canal from closing under the weight of a heavy headphone, a common issue in infants.
- **High Inter-aural Attenuation:** Reduces the risk of the sound "leaking" over to the non-test ear, minimizing the need for **masking**.

Key Points

- Stimulus parameters shape neural responses.
- Different stimuli answer different clinical questions.
- Intensity, rate, and polarity directly affect waveform appearance.
- Default settings are not clinically neutral.
- Always match stimulus choice to the clinical question.

Common Mistakes

- *Using click stimuli to answer frequency-specific questions.*
- *Using fast rates without considering neural effects.*
- *Ignoring polarity when cochlear microphonic is suspected.*

Ethics

- *Clinicians are responsible for stimulus selection.*

Documentation

- *Record stimulus type, intensity, rate, and polarity.*

Many 'ABR problems' are actually stimulus problems.



CHAPTER

11

*Recording Auditory Evoked Responses:
Acquisition Parameters*



*Two recordings can use the same stimulus
and produce different results.*

Why?

Because acquisition parameters decide:

- *what is amplified*
- *what is ignored*
- *what is averaged*
- *and what is filtered out*

Acquisition does not change the nervous system.

*It changes **your window into it.***

Amplification (Gain): Seeing Without Distorting

Gain amplifies the recorded signal.

Too little gain hides responses.

Too much gain exaggerates noise.

Good gain:

- *makes responses visible*
- *without reshaping them*

Gain should reveal—not dramatize.

Averaging: Stability Over Speed

Averaging improves signal-to-noise ratio.

More averages:

- *improve clarity*
- *increase confidence*

Fewer averages:

- *shorten test time*
- *increase uncertainty*

Stopping averaging early to “save time”

often costs more time later.

Filtering: Help or Harm

Filters shape what frequencies are displayed.

Appropriate filtering:

- *improves clarity*
- *removes irrelevant noise*

Overfiltering:

- *distorts waveform morphology*
- *creates false confidence*

Filters should clean the view—

not redraw the picture.

Analysis Time Window

The time window determines what activity is visible.

A short window may:

- *miss delayed responses*

A long window may:

- *introduce unrelated noise*

Choosing the correct window

*is choosing **what you allow yourself to see.***

Artifact Rejection

Artifact rejection protects data quality.

However:

- *overly strict rejection prolongs testing*
- *overly lenient rejection accepts noise*

Balance is essential.

*Artifacts should be managed—
not ignored or feared.*

*Many interpretation errors
are acquisition errors that went unnoticed.*

*Before trusting what you see,
ask how it was acquired.*

– Clinical Summary

*In the clinical measurement of auditory evoked responses (AERs),
acquisition parameters determine how the brain's electrical activity is
captured, cleaned, and processed.*

*These settings are the "receiver" side of the measurement and are
vital for separating the tiny auditory signal from background noise.*

1. Analysis Time (Epoch) and Baseline

Analysis Time is the time window (in milliseconds) after a stimulus during which the computer "listens" for a response.

- **Duration:** Must be long enough to capture the entire wave. For ECochG, this may be as short as **5 ms**; for ABR, **15–20 ms** is recommended (especially for infants or hearing-impaired patients where waves are delayed); for cortical responses, it may exceed **600 ms**.
- **Pre-stimulus Baseline:** Usually the first 10% of the epoch (e.g., 1–2 ms before the sound). This helps the clinician estimate the "noise floor" and provides a stable baseline for measuring wave amplitudes.

2. Electrodes: The Front Line

Electrodes are sensors that passively detect neural activity. Successful recording depends on **impedance** (opposition to electrical flow).

- **Skin Preparation:** The skin must be vigorously scrubbed with an abrasive liquid (like NuPrep) to remove oils and dead skin.
- **Impedance Goals:** Total impedance should be **under 5000 ohms**, and inter-electrode balance should be within **2000 ohms**.
- **Types:** * **Disc:** Reusable metal (gold/silver) cups.
 - **Ear Clips:** Springs that secure electrodes to the earlobe; these often produce larger Wave I amplitudes.
 - **Disposable:** Adhesive pads that are discarded after one use; ideal for infection control in newborns.
 - **TIPtrodes:** Gold-foil-covered foam inserts that act as both an earphone and an ear-canal electrode.

3. Amplification and Signal Processing

Because AERs are microscopic (often less than $0.5 \mu V$), they must be processed through several stages:

- **Amplification:** The signal is typically boosted **100,000 times**.
- **Common Mode Rejection (CMR):** The system subtracts electrical activity that is identical at both electrode sites (noise), while preserving the neural activity that is unique to the auditory pathway.
- **Artifact Rejection:** The computer automatically discards "sweeps" (individual samples) contaminated by excessive movement or electrical spikes. Newer systems use **Weighted Averaging**, which gives less "weight" to noisy samples rather than throwing them away entirely.

4. Filter Settings

Filters eliminate unwanted frequencies that do not contain auditory information.

- **High Pass:** Removes lower frequencies (e.g., set to **30 Hz** for ABR to remove slow EEG waves).
- **Low Pass:** Removes higher frequencies (e.g., set to **3000 Hz** for ABR to remove muscle-related high-frequency noise).
- **Notch Filter:** Designed to remove 60 Hz power line hum.

Caution: This is often avoided in infants as it can distort the actual brainstem response.

5. Signal Averaging and SNR

The **Signal-to-Noise Ratio (SNR)** is the most critical metric in AER.

The signal is enhanced through averaging:

- **The Math:** SNR improves by the **square root of the number of sweeps**. For example, 2000 sweeps will produce a much cleaner wave than 500.
- **The 3:1 Rule:** A response is generally considered reliable when the wave is **three times larger** than the residual background noise.
- **When to Stop:** Averaging should stop once a response is clearly repeatable and the SNR is adequate, rather than stopping at a pre-set number of sweeps.

Common Mistakes

- Ignoring repeatability.

Take-Home Messages

- Repeatability is non-negotiable.



CHAPTER

12

Clinical Applications of Auditory Evoked Responses

Evoked responses become clinically meaningful only when they influence a decision.

They are used to:

- *guide diagnosis*
- *support early intervention*
- *plan rehabilitation*
- *monitor neural integrity*

Without a clinical application, a perfect waveform is just a picture.

Application in Infants and Young Children

Evoked responses help:

- *guide early amplification decisions*
- *support cochlear implant candidacy discussions*
- *reduce diagnostic delay*

In pediatrics, evoked responses often speak before the child can.

Application in Difficult-to-Test Patients

Not all adults cooperate easily.

Evoked responses are valuable in:

- *patients with developmental delay*
- *individuals with cognitive impairment*
- *suspected non-organic hearing loss*
- *medico-legal evaluations*

Objectivity supports fairness—

but interpretation still requires restraint.

Application in Neurodiagnostic Assessment

*Evoked responses also assess **pathway integrity**.*

They may:

- *support suspicion of neural pathology*
- *guide referral to neurology or ENT*
- *complement imaging and clinical findings*

They rarely provide a diagnosis alone.

*They support **clinical reasoning**, not shortcuts.*

Application in Hearing Aid and Implant Pathways

Evoked responses contribute to:

- *pre-fitting assessment*
- *candidacy discussions*
- *post-intervention verification*
- *outcome monitoring*

They guide decisions

without replacing behavioral validation.

Technology decisions without evoked insight are incomplete.

Application in Screening and Follow-Up

Screening is only the beginning.

Evoked responses are essential in:

- *follow-up of failed newborn screening*
- *monitoring at-risk populations*
- *confirming or refining early findings*

A screening result is a question.

Evoked responses help shape the answer.

Limits of Clinical Application

Evoked responses should not be used to:

- *predict speech understanding*
- *guarantee language outcomes*

Using them beyond their scope creates false confidence.

– Clinical Summary

Auditory evoked responses (AERs) are essential tools in clinical audiology, providing objective data that behavioral tests cannot.

By measuring electrical activity at various points along the auditory pathway, clinicians can identify the specific site and nature of auditory dysfunction.

1. Electrocochleography (ECochG)

*ECochG measures the earliest electrical responses, originating from the **cochlea** and the **auditory nerve**.*

- **Wave I Enhancement:** ECochG provides a large, clear Wave I (the Action Potential). This helps identify neural problems by allowing more accurate measurement of the time it takes for a signal to travel from the nerve to the brainstem.
- **Ménière's Disease:** It is a primary diagnostic tool for identifying excessive fluid pressure in the inner ear.
- **Surgical Monitoring:** Used during surgery to provide real-time updates on cochlear health.
- **ANSD Diagnosis:** Helps differentiate between issues in the sensory hair cells versus the auditory nerve in patients with Auditory Neuropathy Spectrum Disorder.

2. Auditory Brainstem Response (ABR)

The ABR is perhaps the most widely used AER, especially in pediatrics. It tracks the signal as it passes through the **brainstem**.

- **Newborn Hearing Screening:** Automated ABR is the "gold standard" for screening infants at birth.
- **Threshold Estimation:** Uses frequency-specific tone bursts to estimate a child's hearing levels without requiring them to respond behaviorally.
- **Neuro-diagnosis:** Detects tumors on the auditory nerve (acoustic neuromas) or demyelinating diseases like Multiple Sclerosis.
- **Cochlear Implant Candidacy:** Helps determine if a child is a candidate for surgery by checking for a lack of response to high-intensity sounds.

- **Brain Death Determination:** Used in intensive care to monitor brainstem integrity in comatose patients.

3. Auditory Steady-State Response (ASSR)

ASSR is a related technique often used when ABR results are inconclusive or when testing patients with **severe-to-profound hearing loss**.

- **Automated Audiograms:** ASSR can automatically create a predicted audiogram, which is vital for fitting hearing aids in infants.
- **Efficiency:** It is particularly useful for assessing multiple frequencies in both ears simultaneously, saving time in pediatric clinics.

4. Cortical Auditory Evoked Responses (ALR & P300)

These "late" responses represent activity in the **auditory cortex** (the high-level processing centers of the brain).

- **Neural Maturation:** ALRs are used to document how an infant's brain develops and "wires itself" after receiving hearing aids or cochlear implants.
- **Auditory Processing Disorders (APD):** Assessments for children who have normal hearing but struggle to understand speech in complex environments.
- **Legal/Forensic Audiology:** Identifying "malingering" (faked hearing loss) in adults seeking financial compensation, as these brain waves are difficult to suppress consciously.

Summary of Clinical Utility

<i>Test</i>	<i>Primary Anatomy</i>	<i>Key Clinical Use</i>
<i>ECochG</i>	Cochlea/8th Nerve	Ménière's diagnosis
<i>ABR</i>	Auditory Brainstem	Newborn screening & Neuro-diagnosis
<i>ASSR</i>	Subcortical/Brainstem	Fitting hearing aids in infants
<i>ALR</i>	Auditory Cortex	Documenting brain maturation

*Table 12.1 Summary of Clinical Utility****Key Points***

- *Evoked responses are critical in pediatrics and difficult-to-test patients.*
- *Never let technology outrun judgment.*

Common Mistakes

- *Using evoked responses as stand-alone diagnostic tools.*
- *Ignoring follow-up needs.*



CHAPTER

13

Efficient Measurement of Auditory Evoked Responses

True efficiency means obtaining *the right information*,
with *the least repetition*,
while *protecting interpretation quality*.

Smart Stimulus Selection

Choosing the correct stimulus saves time.

- Use **clicks** for neural synchrony questions.
- Use **frequency-specific stimuli** for threshold estimation.
- Avoid repeating tests that answer the same question.

One good stimulus beats three unnecessary one

Efficiency in the Real World

In busy clinics:

- infants wake up
- schedules shift
- pressure increases

Efficiency means adapting without lowering standards.

*The fastest path to a decision
is often **doing fewer things better**.*

Why This Chapter Matters

Most clinics do not fail because they lack time.

They fail because time is misused.

Efficient measurement protects:

- *patient comfort*
- *clinician focus*
- *data quality*

*Efficiency done right
improves outcomes.*

– Clinical Summary

*In clinical settings, **speed** is often just as critical as **accuracy**. For an audiologist, efficient measurement of Auditory Evoked Responses (AER) ensures that vital data is collected before a child wakes up or before a surgeon makes a critical move in the operating room.*

Here is a breakdown of the core principles for efficient AER measurement.

1. The Necessity of Speed

While accuracy is the foundation, speed determines feasibility in challenging environments:

- ***Natural Sleep in Pediatrics:*** *Children typically only sleep for short windows. If they wake up, the assessment often cannot continue.*

- ***Intra-operative Monitoring:*** *In the operating room, "old news is no news." The surgical team needs real-time data to make management decisions.*
- ***Clinical Profitability:*** *Prompt data collection improves patient throughput and satisfaction.*

2. Advanced Preparation

Efficiency begins before the patient ever arrives. True preparation means:

- ***Pre-test Checklist:*** *Ensuring all electrodes, skin-prep supplies, and transducer tips are organized and within arm's reach.*
- ***Software Readiness:*** *Having the correct test protocols pre-loaded and biographical data entry completed before the patient is hooked up.*
- ***Setting the Stage:*** *Any preparation done after the patient enters the room is considered "wasted time."*

3. Planning for Every Outcome

An experienced clinician never relies on a single plan. You must have a strategy for two specific scenarios:

- ***Best-Case Scenario:*** *A full, comprehensive evaluation across all frequencies and intensities.*
- ***Worst-Case Scenario (Plan B):*** *A strategy to obtain the **minimum necessary information** for clinical management. If the patient is restless, this might mean testing only the most critical frequency or skipping less vital parts of the battery.*

4. Online Analysis and Record Keeping

Efficiency is maintained by "thinking on your feet" during the recording process:

- **Concurrent Analysis:** While the computer is averaging a response, the clinician should be analyzing previously collected data and marking peaks.
- **Real-time Decision Making:** Using the "silent" time during data collection to plan the next logical step (e.g., deciding whether to increase intensity or switch ears).
- **Documenting Events:** Keeping notes on patient movements, electrical interference, or changes in state allows for meaningful offline analysis later.

Summary Checklist for Efficiency

Factor	Clinical Action
Preparation	Complete all setup before patient contact.
Prioritization	Collect top-priority data first (Threshold vs. Neurological).
Flexibility	Adapt strategy instantly if the patient becomes active.
Productivity	Analyze data while the system is signal-averaging.

Table 13.21 Summary Checklist for Efficiency

Key Points

- Reliable data reduces repeat testing.

Common Mistakes

- Rushing to finish testing.
- Recording excessive data without purpose.
- Confusing speed with competence.

Pitfalls

- *Over-testing “to be safe”*
- *Under-testing to save time*

Ethics

- *Poor-quality data misleads decisions.*

The most efficient test is the one you don’t need to repeat.



CHAPTER

14

Measurement Problems and Solutions

Perfect recordings are rare.

Misleading recordings are common.

*Most clinical errors do not come from lack of knowledge,
but from ignoring obvious measurement problems
and hoping interpretation will fix them.*

It won't.

Problem 1: Excessive Noise***What You See***

- *Unstable baseline*
- *Poor waveform clarity*
- *Inconsistent peaks*

Why It Happens

- *Muscle activity*
- *Poor grounding*
- *Environmental electrical interference*

Solution

- *Stabilize patient state*
- *Improve electrode contact*
- *Reduce environmental noise*
- *Pause rather than force averaging*

Noise is information.

Ignoring it is the mistake.

Problem 2: High or Unequal Electrode Impedance

What You See

- *Asymmetric waveforms*
- *Unreliable repeatability*
- *Unexpected latency shifts*

Why It Happens

- *Poor skin preparation*
- *Dry or damaged electrodes*
- *Rushed setup*

Solution

- *Re-prep skin*
- *Replace electrodes*
- *Balance impedance—not just lower it*

Impedance problems corrupt data silently.

Problem 3: Responses That Appear Once and Disappear

What You See

- *“Nice” waveform in one run*
- *No replication*

Why It Happens

- *Random noise coincidence*
- *Overfiltering*
- *Premature stopping*

Solution

- *Repeat under same conditions*
- *Widen filters*
- *Increase averages*

If it doesn't repeat, it doesn't count.

Problem 4: Artifacts Masquerading as Responses

What You See

- *Sharp peaks*
- *Unphysiological timing*
- *Polarity-sensitive shapes*

Why It Happens

- *Muscle activity*
- *Electrical interference*
- *Stimulus artifact*

Solution

- *Change polarity*
- *Adjust stimulus rate*
- *Improve relaxation*
- *Verify physiological plausibility*

Artifacts are convincing liars.

Problem 5: Inconsistent Results Across Sessions

What You See

- *Different thresholds*
- *Variable morphology*

Why It Happens

- *Different patient state*
- *Different parameters*
- *Different preparation*

Solution

- *Compare conditions—not just waveforms*
- *Standardize protocols*
- *Document differences clearly*

Variation is not always pathology.

Problem 6: Pressure to Conclude Despite Problems

What You See

- *Reports written with disclaimers—but firm conclusions*
- *Decisions made “just to move on”*

Why It Happens

- *Time pressure*
- *External expectations*
- *Fear of uncertainty*

Solution

- *Delay interpretation*
- *Recommend repeat testing*
- *State limitations clearly*

Uncertainty is safer than false certainty.

From Problems to Professionalism

Problems are not failures.

Unacknowledged problems are.

Every problem you identify and manage protects:

- *the patient*
- *the decision*
- *and your professional integrity*

Most medico-legal issues in audiology begin with ignored measurement problems.

This chapter exists to stop that chain early.

– Clinical Summary

*In the clinical practice of recording Auditory Evoked Responses (AERs), **troubleshooting** is a critical skill that distinguishes an expert from a novice. Measurement problems often present as aberrations in the waveform—unusual peaks, excessive noise, or a total lack of response—and must be addressed in real-time while the patient is still "hooked up."*

1. The Troubleshooting Mindset

Troubleshooting is a rational, logical approach to identifying the cause of a measurement failure and finding a feasible solution.

- **Real-Time Analysis:** *Information is most valuable during the acquisition process. Waiting until the waveform is fully averaged to detect a problem is inefficient and may result in lost diagnostic opportunities.*

- **Experience-Driven:** While books provide the theory, troubleshooting skills improve with clinical practice. Every solved problem builds a mental "library" of solutions for future use.

2. Categorizing Measurement Problems

To solve a problem, you must first categorize it. Most AER issues fall into one of three buckets:

I. Subject Factors

These are often known before testing begins and can be accounted for in the interpretation of the results.

- **Maturation & Physiology:** Patient age, gender, and body temperature.
- **Hearing Status:** Existing peripheral hearing loss.
- **State of Arousal:** Muscle tension or restlessness.

II. Operator Errors (Technical Mistakes)

These are entirely within the clinician's control and can usually be fixed immediately.

- **Equipment Settings:** Inappropriate filter settings, too-short analysis time, or excessively fast stimulus rates.
- **Physical Setup:** Improper electrode placement, poor skin preparation (high impedance), or stimulus artifact caused by transducer positioning.

III. Environmental & Instrumentation Artifacts

These are external factors that contaminate the recording, often found in "hostile" environments like the NICU or OR.

- **Electrical Interference:** 60 Hz power line hum or electromagnetic radiation from other medical machinery.
- **Muscular Artifact:** Myogenic noise from a patient's jaw, neck, or eye movements.

3. Practical Solutions

When an "aberration" is detected in the waveform, the clinician should follow a systematic search for the source:

Problem	Potential Solution
High Background Noise	Re-scrub electrode sites to lower impedance; ensure patient is relaxed/sleeping.
Excessive Electrical Artifact	Turn off unnecessary equipment (lights, monitors); switch to insert earphones; check grounding.
Poor Waveform Morphology	Slow down the stimulus rate; check if the filter settings are too narrow.
Missing Peaks (e.g., Wave I)	Use an earlobe electrode instead of mastoid; increase stimulus intensity; use a horizontal electrode array.

Table 14.1 Troubleshooting ABR

Key Points

- Measurement problems are common and predictable.
- Noise, impedance, artifacts, and variability must be addressed—not ignored.



SECTION

2

Short Latency Auditory Evoked Responses



CHAPTER

15

Short Latency Auditory Evoked Responses



Short latency auditory evoked responses provide direct insight into the earliest stages of auditory neural processing.

These responses reflect rapid and highly synchronized neural activity occurring from the cochlea through the auditory nerve and brainstem. Their short timing makes them particularly robust and clinically valuable.

Short latency responses form the foundation of objective auditory assessment. Understanding them allows clinicians to:

- Evaluate neural integrity independent of patient cooperation*
- Differentiate peripheral from neural auditory dysfunction*
- Establish physiologic baselines for more complex evoked responses*

This chapter sets the stage for detailed discussion of ECoChG and ABR in later chapters.

Short latency auditory evoked responses are neural potentials that occur within approximately the first 10 milliseconds following acoustic stimulation.

They are characterized by:

- *Precise timing*
- *High neural synchrony*
- *Relative resistance to attention and cognitive state*

These properties make them ideal for clinical use in infants and medically complex patients.

Physiologic Characteristics

Neural Synchrony

Short latency responses depend on simultaneous firing of large populations of auditory nerve fibers and brainstem neurons.

Disruption of synchrony reduces waveform clarity even if neural structures remain anatomically intact.

Limited Cortical Influence

Because these responses arise early in the auditory pathway, they are minimally affected by:

- *Conscious attention*
- *Cognitive processing*
- *Sleep state*

This explains their reliability across diverse patient populations.

Major Types of Short Latency Responses

Electrocochleography

Electrocochleography reflects activity generated in the cochlea and distal auditory nerve. It provides information about:

- *Cochlear transduction*
- *Auditory nerve onset activity*
- *Inner ear pathophysiology*

ECochG is particularly sensitive to cochlear and peripheral auditory disorders.

Auditory Brainstem Response

The auditory brainstem response reflects neural activity from the auditory nerve through multiple brainstem nuclei. It is the most widely used short latency evoked response in clinical audiology.

ABR is central to:

- *Infant hearing assessment*
- *Neurodiagnostic evaluation*
- *Intraoperative monitoring*

Latency and Generator Considerations

Short latency responses are interpreted primarily through timing relationships rather than amplitude. Latency reflects:

- *Conduction velocity*
- *Synaptic transmission time*
- *Pathway integrity*

Because generators overlap, interpretation is functional rather than anatomically precise.

Clinical Strengths

Short latency responses offer several advantages:

- *High reproducibility*
- *Objective measurement*
- *Minimal influence of arousal*
- *Strong normative data base*

These strengths support their widespread clinical adoption.

Clinical Limitations

Despite their strengths, short latency responses have limitations:

- *Limited sensitivity to higher level auditory processing*
- *Reduced frequency specificity with some stimuli*
- *Dependence on high quality recording conditions*

Understanding these limitations prevents misuse.

Clinical Applications

Short latency responses are applied clinically to:

- *Identify hearing loss in infants*
- *Estimate auditory sensitivity*
- *Detect neural conduction abnormalities*
- *Monitor auditory pathway integrity during surgery*

Their versatility makes them indispensable in modern audiology.

Common Pitfalls

- *Assuming short latency responses reflect conscious hearing*
- *Overinterpreting minor latency variations*
- *Ignoring stimulus and recording effects*
- *Expecting precise anatomic localization*

Red Flags

- *Poor waveform replicability*

- *Latency patterns inconsistent with physiology*
- *Absence of expected response at high intensities*
- *Interpretation without considering stimulus parameters*

Clinical Pearls

- *Short latency responses reflect timing not perception*
- *Neural synchrony is the key determinant of waveform clarity*
- *Latency patterns are more informative than amplitude*
- *Functional interpretation is more accurate than anatomic labeling*

Take-Home Messages

- *Short latency auditory evoked responses occur within the first 10 milliseconds*
- *They reflect early auditory nerve and brainstem activity*
- *High synchrony and precise timing define their clinical value*
- *ECochG and ABR are the primary short latency responses*
- *These responses are foundational for objective auditory diagnosis*



CHAPTER

16

Electrocochleography (ECochG)

Electrocochleography is not a routine test.

*It is a **precision tool**.*

It listens closer than most evoked responses—

closer to the cochlea,

closer to the source,

and closer to the line between physiology and pathology.

Used well, ECochG clarifies.

Used poorly, it confuses.

Discovery and Early Developments

The first paper on ECochG was also the first publication on auditory evoked responses in general. In 1930, Ernest Glen W ever and Charles W . Bray of Princeton University published a two-paragraph summary of observations on auditory physiology investigations in cats. Figure 2.1 shows a photograph of Dr. W ever.



Figure 16.1. Photograph of Ernest Glen Wever (1902-1991) who co-discovered in 1930 with Princeton University colleague CW Bray the cochlear otonmicric (CM) component of electrocochleography (ECochG). (Image courtesy of James W. Hall, III.)

What Is ECochG?

Electrocochleography records **electrical potentials generated in the cochlea and auditory nerve** in response to sound.

It primarily evaluates:

- Cochlear hair cell function
- Auditory nerve activity at its most peripheral level

Unlike ABR, which looks downstream,
ECochG listens at the source.

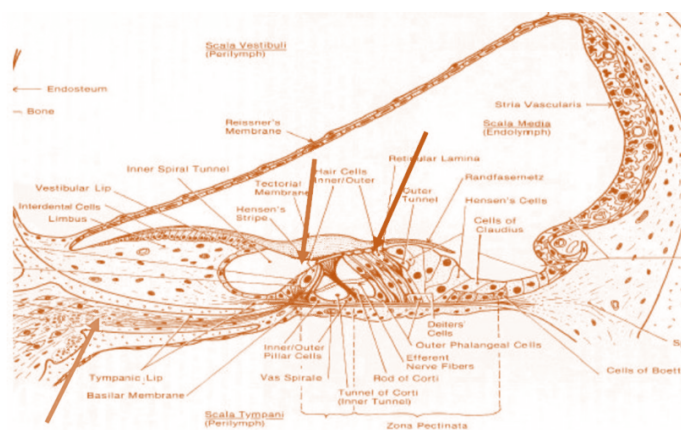


Figure 16.2. Origins of the ECochG components including the cochlear microphonic (blue arrow), the summing potential (red arrow), and the compound action potential (green arrow). (Image courtesy of James W. Hall, III.)

What ECochG Measures

ECochG focuses on three main components:

- ***Cochlear Microphonic (CM)***
Reflects outer hair cell activity and mirrors stimulus waveform.
- ***Summating Potential (SP)***
Represents sustained cochlear response, largely from hair cells.
- ***Action Potential (AP)***
*Represents synchronous firing of auditory nerve fibers
(analogous to ABR Wave I).*

Understanding these components—and their relationships—is essential.

Electrocochleography provides a direct window into cochlear and distal auditory nerve function.

By recording responses generated at the earliest stages of auditory processing, ECochG offers unique diagnostic insight that cannot be obtained from later latency responses alone.

This chapter explains how ECochG works, what it measures, and how it is applied clinically.

ECochG is often misunderstood or underutilized.

A clear understanding allows clinicians to:

- *Assess cochlear transduction and auditory nerve onset activity*
- *Differentiate cochlear from neural dysfunction*
- *Support diagnosis in complex auditory disorders*
- *Complement findings from ABR and other evoked responses*

Electrocochleography is the recording of electrical potentials generated in the cochlea and distal auditory nerve in response to acoustic stimulation.

These potentials occur within the first few milliseconds after stimulus onset and represent the earliest measurable auditory evoked activity.

Components of the ECochG Response

Cochlear Microphonic

The cochlear microphonic reflects receptor potential activity of outer hair cells. Key features include:

- *Waveform that mirrors the acoustic stimulus*
- *Sensitivity to stimulus polarity*
- *Presence indicating functional outer hair cells*

The cochlear microphonic is not a neural response but an electrical representation of mechanical transduction.

Summating Potential

The summating potential represents a direct current shift related to hair cell activity.

It reflects nonlinear cochlear mechanics and contributes to assessment of inner ear function.

Alterations in the summating potential are associated with certain cochlear pathologies.

Compound Action Potential

The compound action potential reflects the synchronous onset firing of auditory nerve fibers.

It is analogous to Wave I of the auditory brainstem response and provides information about:

- *Auditory nerve integrity*
- *Neural synchrony at stimulus onset*

Recording Techniques

Electrode Placement Options

ECochG can be recorded using different electrode locations, including:

- *Ear canal electrodes*
- *Tympanic membrane electrodes*
- *Transtympanic electrodes*

Closer proximity to the cochlea results in larger response amplitudes but may increase invasiveness.

Stimulus Considerations

ECochG responses are influenced by:

- *Stimulus intensity*
- *Stimulus polarity*
- *Stimulus type*

Polarity manipulation is essential for separating cochlear microphonic activity from neural components.

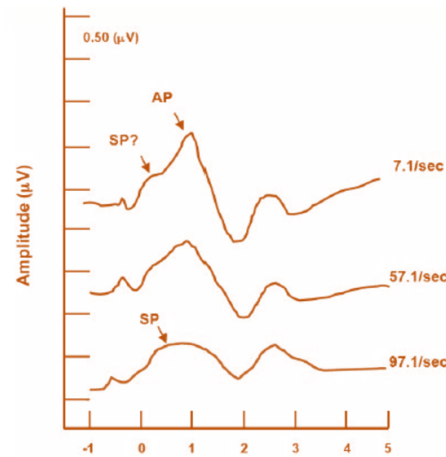


Figure 16.3. Effect of stimulus rate on the SP versus AP components of EcochG. (Image courtesy of James W. Hall, III.)

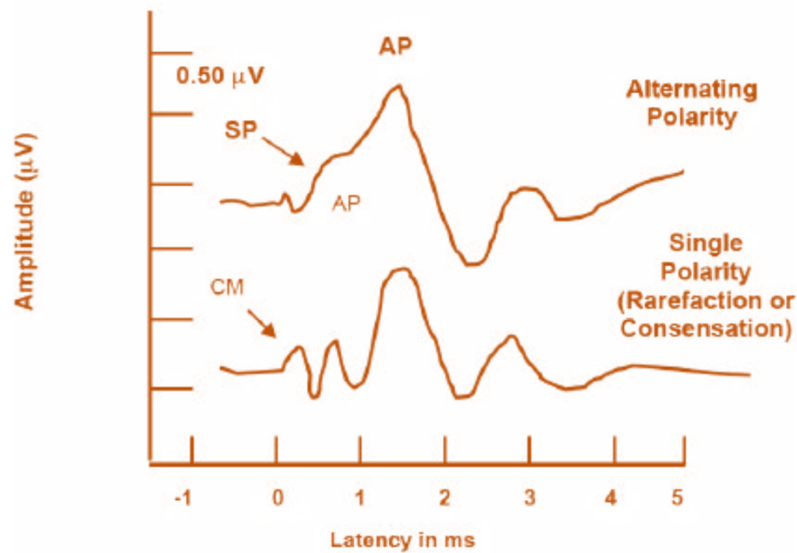


Figure 16.4. Illustration of the effect of stimulus polarity on components of EcochG. (Image courtesy of James W. Hall, III.)

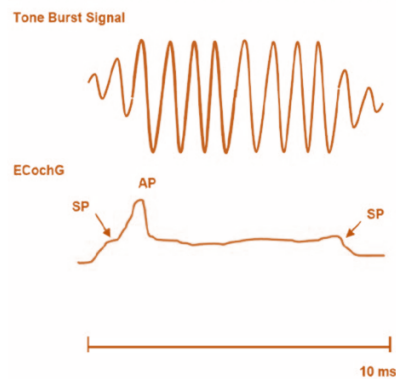


Figure 16.5. Relation between tone burst stimulus duration and the SP versus AP components of EcochG. (Image courtesy of James W. Hall, III.)

Physiologic Interpretation

Each ECochG component reflects a different aspect of cochlear and auditory nerve function. Interpretation requires understanding that:

- *Hair cell and neural responses coexist*
- *Components overlap in time*
- *Abnormalities may selectively affect one component*

Pattern recognition is more informative than isolated measurements.

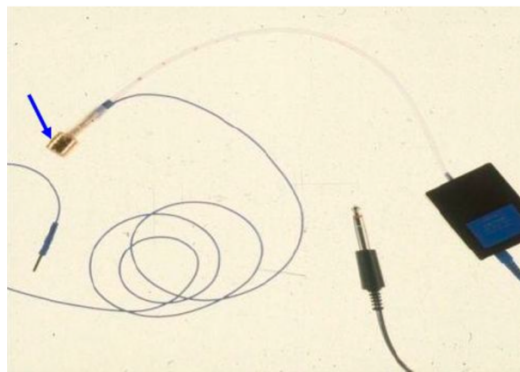


Figure 16.6. TIPtrode combining insert earphones with an external ear canal electrode design. Arrow identifies the gold foil covered foam insert cushion coupled to an electrode wire with a special alligator clip.(Image courtesy of James W. Hall, III.)

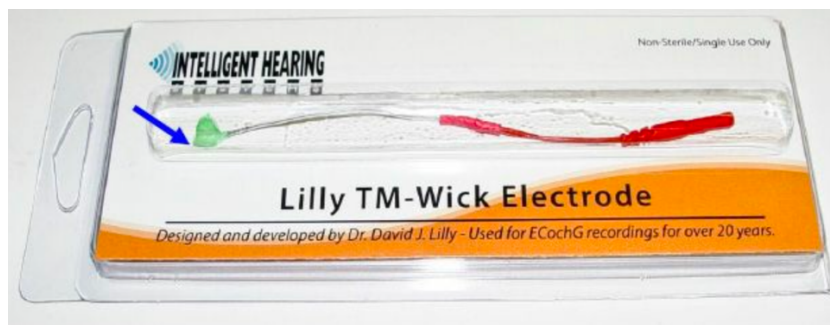


Figure 16.7. The Lilly Wick TM electrode with an arrow pointing to the saline soaked cotton that makes contact with the tympanic membrane (Courtesy of Intelligent Hearing Systems).



Figure 16.8. Sub-dermal needle used for trans-tympanic promontory measurement of ECoG. Arrow points to the shaft of the needle. (Image courtesy of James W. Hall, III.)

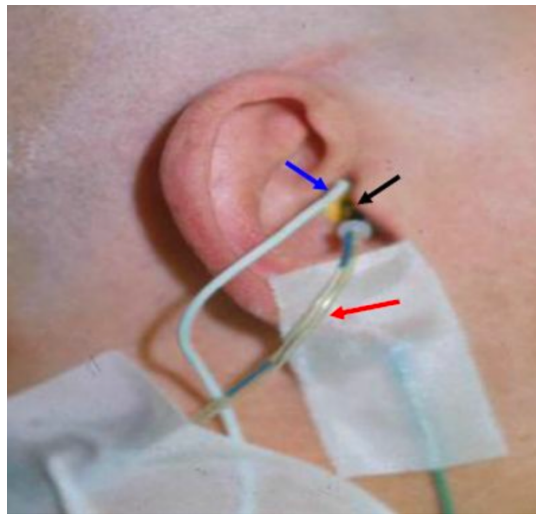


Figure 16.9. Insert earphone tubing and foam cushion and wire for a trans-tympanic needle electrode immediately prior to intra-operative neurophysiological monitoring with a combination ECoG and ABR technique. Arrows point to yellow insert cushion, insert tubing (red arrow), and white electrode wire. (Image courtesy of James W. Hall, III.).

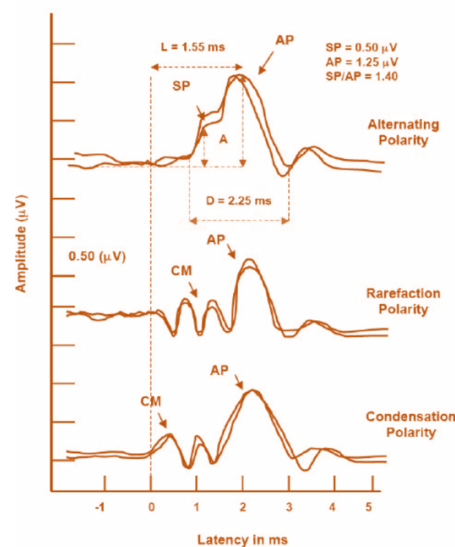


Figure 16.10. Analysis of latency and amplitude of the ECoG components

Test Protocol

Stimulus Parameters. A guideline for stimulus parameters in a clinically useful test protocol for recording ECochG is summarized as follows:

Parameter	Suggestion	Rationale/Comment
Transducer	ER-3A	Permits TIPtrode usage Secures trans-tympanic electrode wire
Type	Click	Produces robust response/only Evaluates cochlear function in basal turn Tone bursts can be used
Duration	0.1-ms	Onset response Longer tone burst duration to verify SP component, e.g., 2-10-2 cycle duration
Polarity	Alternating Single polarity	For recording SP component (cancels out CM) For recording CM component (rarefaction and condensation separately)
Rate	7.1/sec	Low rate enhances the N1 (AP) component Rapid rate is useful for SP delineation (>91/sec)
Intensity	70 to 90 dB nHL	Produces robust response No SP below about 50 dB
Masking	None	Never necessary Response generated by test ear
Presentation	Ear Mode	Monaural Air conduction

Table 16.1. protocol for recording ECochG. (courtesy of James W. Hall, III.).

Clinical Applications

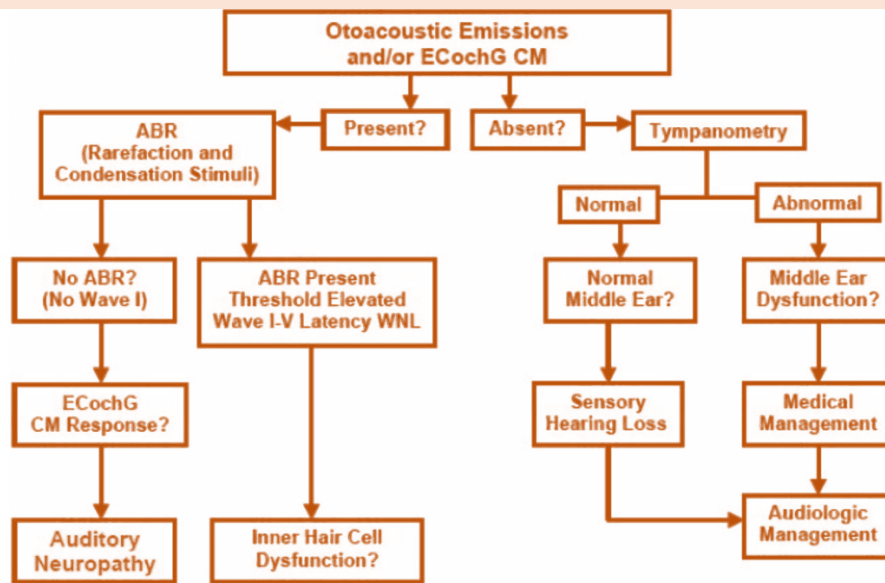
Assessment of Cochlear Function

ECochG provides objective information about cochlear mechanics and auditory nerve activation, supporting diagnosis of inner ear disorders.

Auditory Neuropathy Spectrum Disorder

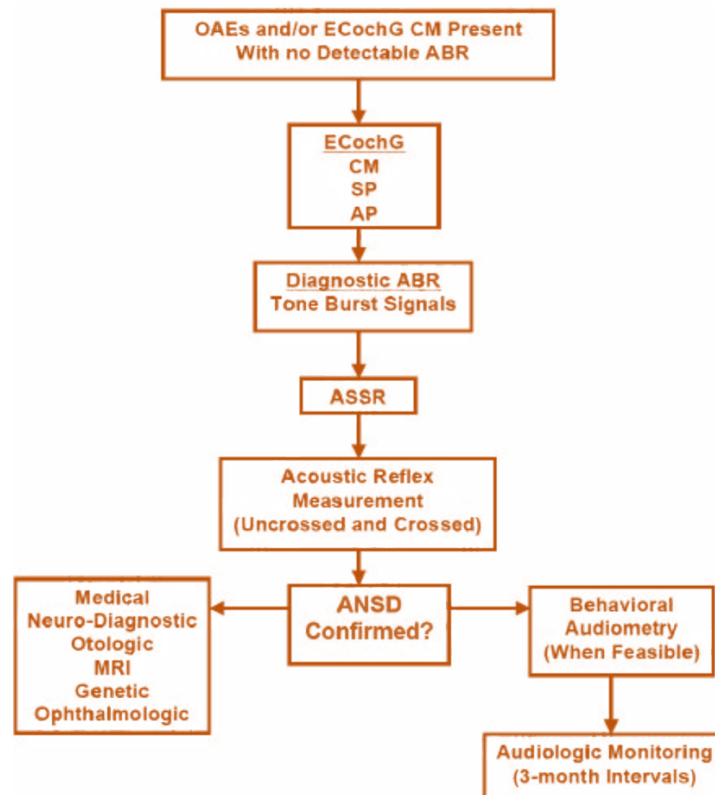
In auditory neuropathy, ECochG often demonstrates preserved cochlear microphonics with absent or abnormal neural responses. This dissociation is a key diagnostic feature.

identification of auditory neuropathy spectrum disorder (ANSD)



Flowchart 16.1. Flowchart illustrating an approach for identification of auditory neuropathy spectrum disorder (ANSD) (courtesy of James W. Hall, III.).

diagnosis of auditory neuropathy spectrum disorder (ANSD)



Flowchart 16.2. Flowchart illustrating an approach for diagnosis of auditory neuropathy spectrum disorder (ANSD) (courtesy of James W. Hall, III.).

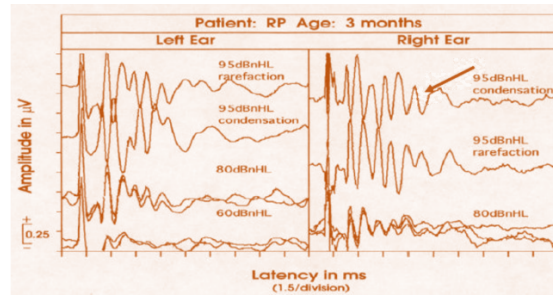


Figure 16.3. Waveforms recorded during measurement of ABR from a 3-month old child with the diagnosis of auditory neuropathy spectrum disorder (ANS). Only CM activity was detected (see arrow). (courtesy of James W. Hall, III.).

Meniere Disease and Inner Ear Disorders

ECochG has been used to support diagnosis of endolymphatic hydrops by evaluating relationships between summing and action potentials. Findings must be interpreted cautiously and in conjunction with clinical symptoms.

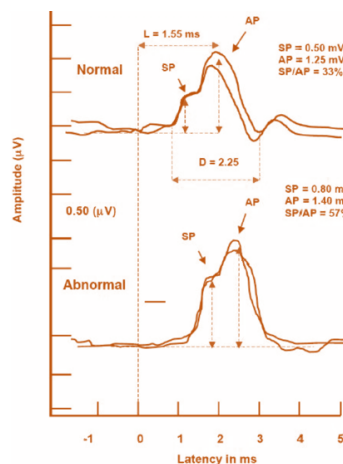


Figure 16.6. Analysis of ECochG SP/AP ratio in Ménière's disease. Blue arrows indicate calculations of SP and AP amplitude from a common baseline. (courtesy of James W. Hall, III.).

Intraoperative Monitoring

ECochG may be applied during surgical procedures to monitor cochlear and auditory nerve function in real time, supporting hearing preservation strategies.

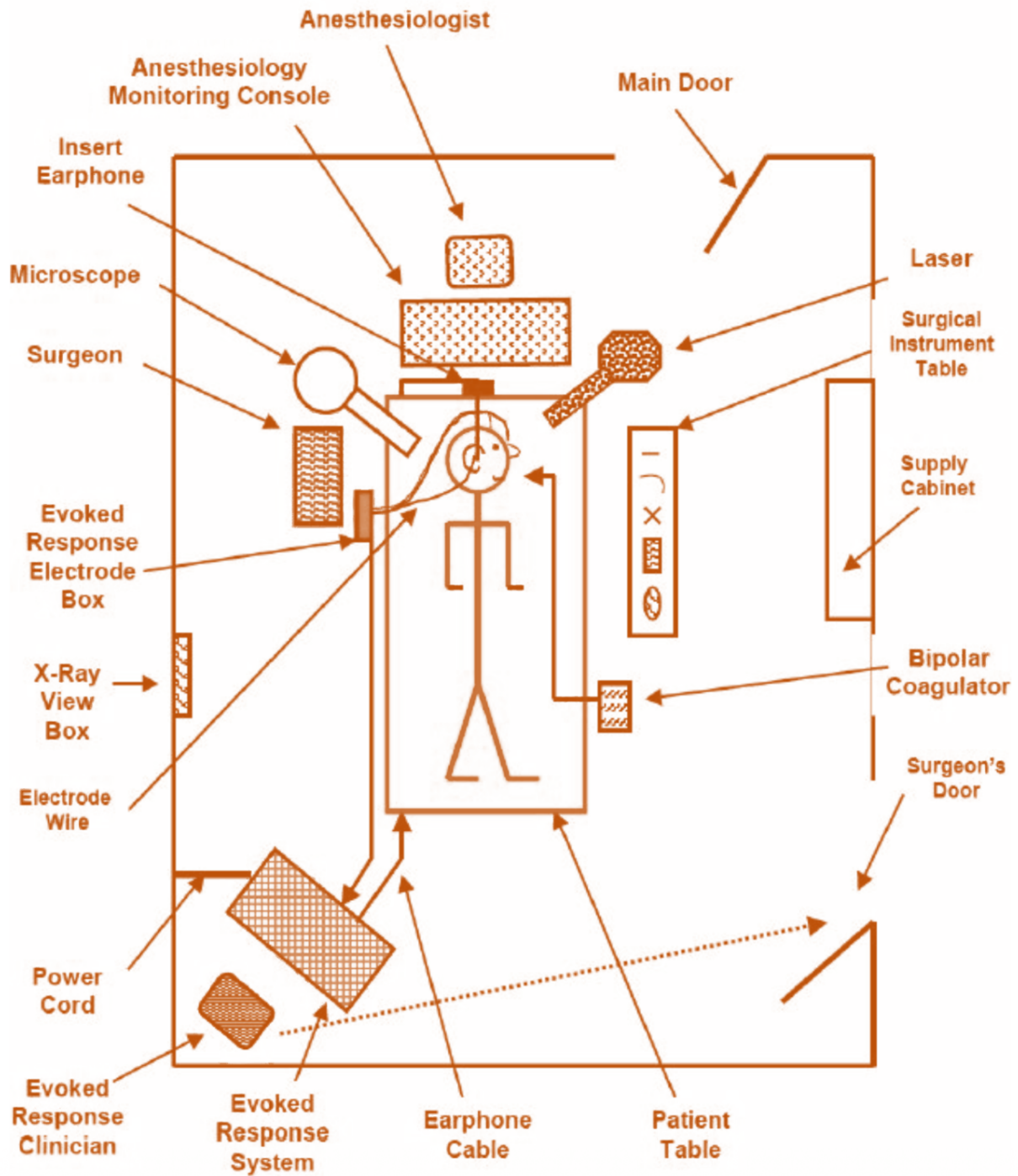


Figure 16.7. Layout for an operating room where intra-operative neurophysiological monitoring is performed

Limitations of ECochG

ECochG has important limitations:

- *Limited availability and expertise*
- *Sensitivity to electrode placement*
- *Overlap of response components*
- *Lack of universally accepted diagnostic criteria*

It should be used as a complementary tool rather than a standalone diagnostic test.

– Clinical Summary

*This overview of **Electrocochleography (ECochG)** covers the history, anatomy, and technical parameters required for this specialized auditory evoked response. ECochG measures the electrical activity of the **cochlea** and the **auditory nerve** within the first 2–3 milliseconds following a sound.*

1. The Three Components of ECochG

An ECochG waveform consists of three distinct potentials, each originating from a different part of the inner ear:

- ***Cochlear Microphonic (CM):*** *An alternating current (AC) potential generated primarily by the **outer hair cells**. It mimics the waveform of the stimulus. Using alternating polarity stimuli cancels the CM out, which is often necessary to see the other components.*
- ***Summating Potential (SP):*** *A direct current (DC) potential generated by the **inner hair cells**. It represents the non-linear*

distortion of the cochlea and is a key marker for Ménière's disease.

- **Action Potential (AP):** *The largest component, representing the synchronous firing of the **auditory nerve fibers**. The AP is the exact same electrical event as **Wave I of the Auditory Brainstem Response (ABR)**.*

2. Historical Context: A Series of Firsts

*ECochG holds a special place in history as the **first** auditory evoked response ever published.*

- **1930:** *Wever and Bray discovered the CM in cats, noticing that auditory nerve impulses could reproduce speech with "great fidelity."*
- **1940s–50s:** *Lempert and Ruben began recording ECochG in humans, initially requiring perforated eardrums or surgical exposure.*
- **1960s:** *The development of the **averaging computer** by G.D. Dawson allowed these tiny signals to be extracted from background noise without surgery.*
- **Late 1960s:** *The **Trans-tympanic (TT)** needle technique was developed, allowing recording through an intact eardrum.*

3. Electrode Options: Proximity is Power

*The quality of an ECochG recording is almost entirely dependent on how close the electrode is to the cochlea ("**near-field**" vs. "**far-field**").*

<i>Electrode Type</i>	<i>Placement</i>	<i>Amplitude</i>	<i>Clinical Utility</i>
<i>Trans-tympanic (TT)</i>	<i>Needle through the TM onto the promontory.</i>	<i>Very High (10-20 μ V)</i>	<i>Gold standard for surgery and Ménière's.</i>
<i>Tympanic Membrane (TM)</i>	<i>"Wick" electrode resting against the eardrum.</i>	<i>Moderate (> 1.0 μ V)</i>	<i>Optimal non-invasive clinical choice.</i>
<i>TIPtrode</i>	<i>Gold-foil foam insert in the ear canal.</i>	<i>Low (< 0.6 μ V)</i>	<i>Good for Wave I, poor for SP detection.</i>

Table 16.2

4. Key Test Parameters

To get a clean ECochG, the "recipe" for the stimulus and acquisition must be precise:

- **Stimulus:** High-intensity **Clicks** (80–95 dB nHL) are standard. **Tone Bursts** are used for frequency-specific data or suspected Ménière's.
- **Polarity:** **Alternating polarity** is used to cancel the CM and reveal the SP and AP. **Single polarity** (rarefaction or condensation) is used specifically to look for the CM in cases of Auditory Neuropathy (ANSN).
- **Rate:** Slower rates (e.g., **7.1/sec**) yield larger AP amplitudes. Very fast rates (>90/sec) are used to "fatigue" the AP, making the SP easier to measure.

- **Filters:** Typically **10 Hz to 1500/3000 Hz**. A low high-pass setting is needed to capture the DC-like Summating Potential.

5. Waveform Analysis Strategies

Clinicians look at four main metrics to diagnose pathology:

1. **SP/AP Amplitude Ratio:** Dividing the size of the SP by the AP. A ratio higher than 0.40 (40%) is often indicative of **Ménière's disease**.
2. **Latency:** Comparing the timing of the AP in rarefaction vs. condensation. Significant shifts can signal endolymphatic hydrops.
3. **Duration/Width:** Measuring the total time of the SP-AP complex.
4. **Area Under the Curve:** A newer method that combines amplitude and duration data for better diagnostic sensitivity.

Electrocochleography (ECochG) clinical applications highlights its transformation from a specialized test for Ménière's disease into a multifaceted tool essential for pediatric diagnostics, neurology, and surgical monitoring.

1. Auditory Neuropathy Spectrum Disorder (ANSD)

ANSD is a complex auditory disorder where the inner ear functions normally, but the transmission of signals to the brain is disorganized or absent. ECochG is the most sensitive tool for identifying where the breakdown occurs.

The Diagnostic Pattern

- **Cochlear Microphonic (CM):** Present and often robust, confirming that outer hair cells are working.
- **Summating Potential (SP):** May be present (suggesting inner hair cell integrity) or absent.
- **Action Potential (AP):** Usually absent or severely distorted, indicating a failure at the synapse or the auditory nerve itself.
- **The "Polarity Test":** In ANSD, the CM flips perfectly when switching from rarefaction to condensation clicks. In a true ABR, the waves do not flip. Adding these two polarities results in a "flat line," which can lead to a false diagnosis of total deafness if the clinician isn't careful.

Clinical Management

Intervention for ANSD is highly individualized. While early opinions discouraged hearing aids, recent data suggest many children benefit from them. Cochlear implants are also highly successful for ANSD patients, particularly those whose dysfunction is at the inner hair cell level (pre-synaptic).

2. Diagnosis of Ménière's Disease

Ménière's disease (endolymphatic hydrops) is caused by excessive fluid pressure in the inner ear. ECochG provides objective evidence of this "hydrops."

- **Enlarged SP:** The increased pressure distorts the basilar membrane, causing the Summating Potential to become abnormally large.

- **The SP/AP Ratio:** This is the most common diagnostic metric. A ratio exceeding **0.40 (40%)** is typically considered positive for Ménière's.
- **Testing during Symptoms:** The test is most sensitive when the patient is currently experiencing aural fullness, vertigo, or fluctuating hearing loss.

3. Intra-operative Monitoring

ECochG is a "near-field" recording, meaning the electrode is very close to the signal source. This provides several advantages during brain surgery (e.g., acoustic tumor removal):

- **Speed:** A clear response can be obtained in **under 10 seconds** (compared to several minutes for ABR), providing the surgeon with near real-time feedback.
- **Ear-Specific:** Confirms that the cochlea is still receiving blood supply during tumor dissection.
- **Wave I Enhancement:** Provides a clear marker to calculate "inter-wave latencies," which helps distinguish between minor nerve stretching and permanent damage.

4. Other Specialized Pathologies

- **Superior Semicircular Canal Dehiscence (SSCD):** Patients with a "hole" in the bone of the inner ear often show an abnormally high SP/AP ratio, similar to Ménière's.
- **Sudden Hearing Loss:** ECochG can help predict recovery; the presence of a CM often indicates a better prognosis for hearing return.

- **Perilymph Fistula:** Unstable ECochG responses during changes in physical pressure (e.g., holding breath) can suggest a fluid leak in the inner ear.

5. Electrical Compound Action Potential (ECAP)

For patients with **Cochlear Implants (CI)**, the auditory nerve is stimulated electrically rather than acoustically.

- **Telemetry:** Using the implant itself to record the nerve's response.
- **Objective Mapping:** Used in infants to determine the "T" (threshold) and "C" (comfort) levels of the implant without requiring the baby to tell the audiologist what they hear.
- **Device Integrity:** Confirms that the electrodes are properly placed and functioning immediately after surgery.

Summary of Clinical Utility

Application	Key Marker	Value to Clinician
ANSD	CM present / AP absent	Localizes dysfunction to the synapse/nerve.
Ménière's	SP/AP Ratio > 0.40	Provides objective proof of fluid pressure.
Surgery	Real-time AP amplitude	Prevents permanent hearing loss during tumor removal.
Cochlear Implants	ECAP presence	Confirms nerve survival and helps program the device.

Table 16.3 Summary of Clinical Utility

Common Pitfalls

- *Misinterpreting cochlear microphonics as neural responses*

Clinical Pearls

- *ECochG reflects the earliest stages of auditory processing*
- *Cochlear microphonics indicate hair cell function not hearing perception*
- *Polarity manipulation is essential for accurate interpretation*
- *ECochG complements ABR rather than replacing it*

Take-Home Messages

- *Electrocochleography records cochlear and distal auditory nerve activity*
- *It includes cochlear microphonic, summing potential, and compound action potential*
- *ECochG provides unique insight into cochlear and neural synchrony*
- *Clinical application requires careful technique and interpretation*
- *ECochG is most powerful when integrated with other evoked responses*

Key Points

- *ECochG records cochlear and auditory nerve potentials.*
- *It evaluates CM, SP, and AP components.*
- *It is useful for specific diagnostic questions—not routine testing.*
- *Interpretation depends heavily on recording method.*

Common Mistakes

- *Ignoring recording method limitations.*

Ethics

- *Overconfidence may lead to unnecessary intervention.*

Documentation

- *Document electrode type and placement.*
- *Record stimulus parameters and polarity.*

Report Writing

- *Avoid absolute diagnostic language.*
- *Recommend correlation with other tests.*



CHAPTER

17

Introduction to Auditory Brainstem Response (ABR)

The auditory brainstem response represents the most widely used and clinically influential auditory evoked potential.

Its strength lies in its ability to provide objective information about auditory nerve and brainstem function with high reliability across patient populations.

This chapter establishes the foundational principles necessary for understanding ABR generation, recording, and interpretation.

ABR is central to modern audiology practice.

A solid foundation allows clinicians to:

- Interpret waveforms with physiologic confidence*
- Distinguish normal from abnormal neural timing*
- Apply ABR appropriately in pediatric and neurologic settings*
- Avoid common misinterpretations that lead to diagnostic error.*



Figure 17.1 . Don Jewett

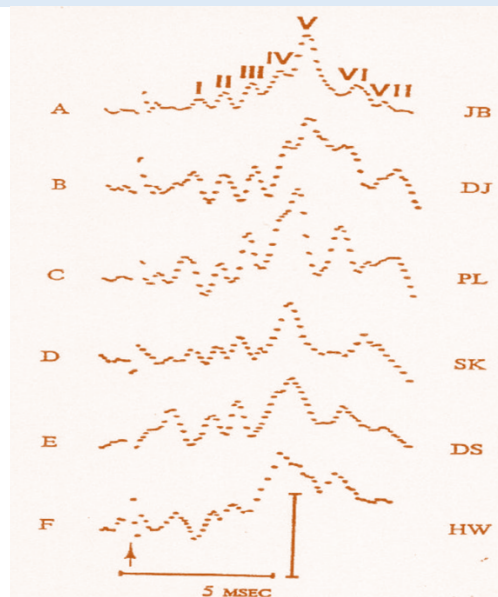


Figure 17.2. Waveforms from the Jewett & Willston (1971) article illustrating the high level of inter-subject consistency characterizing the ABR.

Definition of the Auditory Brainstem Response

The auditory brainstem response is a series of time locked electrical potentials generated by synchronous neural activity within the auditory nerve and brainstem following acoustic stimulation. These responses occur within approximately the first 10 milliseconds after stimulus onset.

Physiologic Basis of the ABR

ABR generation depends on:

- *Rapid activation of auditory nerve fibers*
- *High neural synchrony at stimulus onset*
- *Sequential transmission through brainstem pathways*

Because ABR reflects onset activity, it is sensitive to disruptions in neural timing rather than sustained neural firing.

ABR Waveform Components

The ABR waveform consists of a series of peaks labeled using Roman numerals.

Each peak reflects overlapping activity from multiple neural generators rather than a single anatomic site.

Key concepts include:

- *Early waves reflect peripheral and lower brainstem activity*
- *Later waves reflect progressively higher brainstem involvement*
- *Functional interpretation is more accurate than strict anatomic labeling*

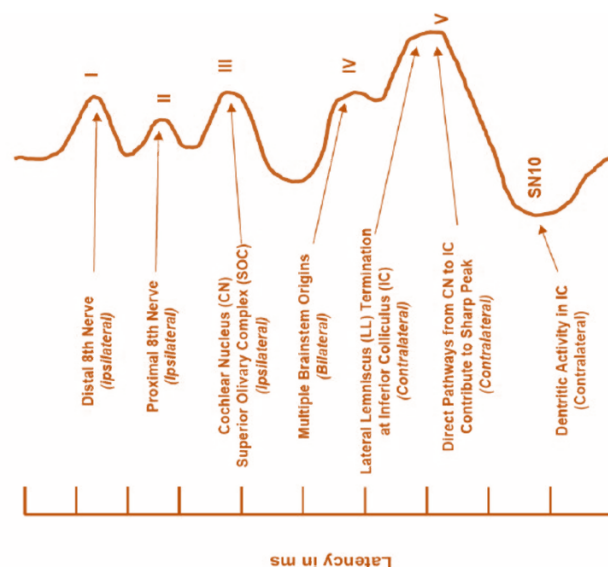


Figure 17.3. Major waves in the auditory brainstem response and generators based on research findings.

Latency and Timing Characteristics

Latency is the primary analytic feature of the ABR. It reflects the time required for neural signals to travel through the auditory pathway.

Latency analysis includes:

- *Absolute latency of individual waves*
- *Interpeak latency representing transmission between neural regions*
- *Interaural latency comparisons as an internal control*

Latency patterns provide insight into neural conduction efficiency.

Amplitude Considerations

ABR amplitudes are small and variable. Unlike latency, amplitude:

- *Varies significantly across individuals*
- *Is sensitive to recording conditions*
- *Is less reliable for diagnostic decision making*

Amplitude should be interpreted cautiously and always in context.

Neural Synchrony and ABR Integrity

ABR depends critically on neural synchrony.

Conditions that disrupt synchrony may:

- *Degrade waveform morphology*
- *Prolong latencies*
- *Eliminate identifiable peaks*

Normal cochlear function alone is insufficient to guarantee a normal ABR.

Effects of Stimulus Parameters on ABR

ABR characteristics are influenced by:

- *Stimulus intensity which affects latency and waveform visibility*
- *Stimulus rate which stresses neural conduction*
- *Stimulus polarity which assists in identifying cochlear microphonics*

Understanding these effects is essential for accurate interpretation.

Clinical Strengths of ABR

ABR offers several advantages:

- *Objective assessment independent of patient cooperation*
- *High reproducibility*
- *Strong normative data*
- *Applicability across ages and clinical settings*

These strengths explain its widespread clinical use.

Clinical Limitations of ABR

Despite its value, ABR has limitations:

- *It does not measure conscious hearing perception*
- *It has limited frequency specificity with certain stimuli*
- *It cannot localize pathology with absolute anatomic precision*

Recognizing these limitations prevents misuse.

Common Pitfalls

- *Treating ABR as a behavioral hearing test*
- *Overinterpreting small latency differences*
- *Ignoring recording quality and replication*
- *Applying adult norms to pediatric cases*

Red Flags

- *Absence of Wave V at high stimulus levels*

- *Marked interaural latency asymmetry*
- *Non replicable waveforms*
- *Latency patterns inconsistent with physiologic expectations*

Clinical Pearls

- *ABR reflects neural timing not auditory experience*
- *Latency is more informative than amplitude*
- *Replication confirms physiologic validity*
- *Interpretation must integrate stimulus and patient factors*
- *Functional reasoning is superior to rigid localization*

Take-Home Messages

- *ABR is a short latency evoked response generated by auditory nerve and brainstem activity.*
- *Neural synchrony and precise timing define its waveform*
- *Latency analysis is central to interpretation*
- *ABR is objective but not a measure of perception*
- *Foundational understanding is essential for advanced clinical application*



CHAPTER

18

*Auditory Brainstem Response
Historical Perspective*

ABR did not begin as an audiology test.

*It began as a **neurophysiological discovery**.*

Long before ABR became a routine part of pediatric hearing assessment,

it was a scientific attempt to answer a deeper question:

Can we listen to the brain without asking the patient to speak?

Before ABR: When Audiology Had to Wait

Before ABR, audiology depended almost entirely on behavior.

If the patient could not respond:

- *diagnosis was delayed*
- *intervention was postponed*
- *decisions were based on assumptions*

Infants waited.

Children waited.

Outcomes waited.

Silence was not neutral—it was harmful.

The Birth of ABR: From Curiosity to Breakthrough

In the early 1970s, researchers discovered that brief sounds could evoke

tiny, time-locked electrical responses from the auditory pathway.

These responses:

- *occurred within the first 10 milliseconds*
- *were repeatable*
- *did not require attention or cooperation*

For the first time,

*the brainstem spoke **without permission from behavior.***

This was revolutionary.

ABR was not invented to measure hearing thresholds.

*It was discovered while exploring **neural conduction and synchrony.***

Audiology adopted it later.

From Neuroscience to Clinical Tool

Initially, ABR was used to:

- *study auditory pathway integrity*
- *identify neurological lesions*
- *support neurodiagnostic evaluation*

The Expansion Era: Power Grows Faster Than Thinking

As ABR technology improved:

- *equipment became smaller*
- *waveforms became cleaner*
- *testing became faster*

ABR moved from research labs to clinics to screening programs.

Its power expanded rapidly.

Clinical thinking did not always keep pace.

ABR started being treated as:

- *definitive*
- *exact*
- *final*

That was never its original purpose.

ABR in Pediatrics: A Turning Point

When ABR entered pediatric audiology, it became one of the most influential tools in early-life decision-making.

For the first time:

- *infants could be assessed objectively*
- *intervention could begin early*
- *waiting was no longer mandatory*

This saved countless children from delayed language development.

*But it also meant that **mistakes became permanent faster.***

History taught us this lesson the hard way.

What History Warns Us About

ABR's history shows a pattern:

Technology advances.

Confidence increases.

Overuse follows.

Then reality intervenes.

Many of today's best-practice principles exist because earlier generations learned what happens when ABR is trusted **too much, too fast, or alone**.

History is not background.

It is instruction.

Why This Historical Perspective Matters

Understanding where ABR came from changes how you use it.

You stop asking:

"What does this waveform say?"

And start asking:

"What was ABR designed to answer in the first place?"

That question protects patients.

– Clinical Summary

The clinical measurement of the **Auditory Brainstem Response (ABR)** is a relatively young field, having evolved from obscure physiological observations in the late 1960s to a global standard of care by the 1980s. Its history is marked by the transition from manually recorded "artifacts" to sophisticated, computer-averaged diagnostic waveforms.

1. Early Discoveries (1967–1970)

Before the ABR was formally recognized, researchers like **Harvey Sohmer** and **Moshe Feinmesser** (1967) observed negative peaks following the initial cochlear response. They correctly hypothesized that these were "volume-conducted" signals from brainstem nuclei. Similarly, **Ernest Moore** documented these waves in his 1971

dissertation, though his findings were initially met with skepticism by the scientific community.

2. The Jewett & Williston Revolution (1971)

The formal discovery is credited to **Don Jewett**, who initially dismissed the early waves as artifacts. However, alongside Michael Romano and John Williston, he published the seminal 1971 paper in the journal *Brain*.

Major Contributions of the 1971 Paper:

- **Nomenclature:** Jewett established the convention of labeling the waves with **Roman Numerals (I–VI)**, a system still used today.
- **Neural Generators:** He identified Wave I as arising from the eighth nerve and Wave II from the cochlear nuclei.
- **Subject State:** He noted that, unlike later cortical responses, the ABR is **independent of sleep or arousal**, making it ideal for testing infants or comatose patients.
- **Wave V Stability:** Jewett identified Wave V as the most robust and easiest to record, making it the primary basis for comparing hearing across individuals.

3. Timeline of Major Developments

The 1970s and 80s saw an explosion of research that defined how we use ABR today.

Year	Milestone Developer	Clinical Contribution
1974	Hecox & Galambos	First description of ABR in infants/children.

<i>Year</i>	<i>Milestone Developer</i>	<i>Clinical Contribution</i>
1977	Selters & Brackmann	Proved ABR's power in detecting acoustic tumors .
1978	Don & Eggermont	Developed frequency-specific ABR using masking.
1980	Jerger & Hall	Studied the significant effects of age and gender on latencies.
1985	Hall et al.	Applied ABR in the determination of brain death .
1987	Hall, Ruth & Kileny	First clinical trial of automated ABR for infant screening.

Table 18.1

4. Emergence of Clinical Hardware

Early ABR testing was cumbersome until the late 1970s, when specialized medical hardware reached the market.

- **The Nicolet CA-1000:** This iconic system featured a cart with large wheels and a manual X-Y plotter to draw waveforms onto paper, as permanent digital storage was not yet available.
- **Transition to Software:** These "knob-and-button" systems eventually gave way to the PC-based platforms used in modern clinics.

5. Clinical Rationale

Jewett and Williston's work fundamentally changed audiology by providing a tool that was:

1. **Reliable:** *Replicable across different subjects and laboratories.*
2. **Objective:** *Did not require the patient to participate or be awake.*
3. **Site-Specific:** *Sensitive enough to distinguish between a problem in the ear and a problem in the brainstem.*



CHAPTER

19

ABR Recording Parameters and Clinical Protocols

Accurate auditory brainstem response results depend as much on recording parameters as on physiologic integrity of the auditory system.

This chapter explains how ABR recording parameters are selected, optimized, and applied clinically to ensure valid and interpretable results.

Recording protocols must be intentional and clinically driven.

Patient Preparation and Test Conditions

Reliable ABR recording requires minimizing physiologic and environmental noise. Key considerations include:

- *Patient relaxation or natural sleep*
- *Minimal muscle activity and movement*
- *Comfortable positioning*
- *Stable recording environment*

Patient state is a critical determinant of data quality, especially in infants and young children.

Electrode Impedance and Balance

Low and balanced electrode impedance is essential for reducing noise. Clinical guidelines include:

- *Keeping electrode impedance low*
- *Maintaining minimal interelectrode impedance differences*
- *Rechecking impedance throughout testing if waveforms degrade*

Poor impedance control directly compromises signal to noise ratio.

Filter Settings

Filter settings determine which frequency components of the neural response are recorded. Appropriate filter selection:

- *Preserves waveform morphology*
- *Maintains latency accuracy*
- *Reduces low frequency drift and high frequency noise*

Inconsistent filter settings invalidate comparison with normative data.

Analysis Time Window

The analysis time window must be long enough to capture all relevant waveform components. Considerations include:

- *Shorter windows for high intensity stimuli*
- *Longer windows for lower intensities or pediatric testing*
- *Consistent window use across recordings*

An inadequate time window may truncate late components and distort interpretation.

Number of Averages

Increasing the number of stimulus presentations improves signal to noise ratio. Clinical considerations include:

- *Balancing test time with waveform quality*
- *Increasing averages near threshold levels*
- *Avoiding excessive averaging that may mask changes in patient state*

A sufficient number of averages is essential for confirming true responses.

Artifact Rejection Criteria

Artifact rejection systems exclude contaminated sweeps from averaging. Proper use requires:

- *Setting rejection thresholds appropriate to patient state*
- *Monitoring raw EEG activity*
- *Avoiding excessive rejection that eliminates true responses*

Artifact control supports waveform clarity but cannot replace patient management.

Replication Strategy

Replication is the primary method for confirming physiologic validity. Clinical protocols should include:

- *At least two replicable recordings at each critical condition*
- *Consistent latency and morphology across replications*
- *Verification before proceeding to interpretation*

Non replicable responses should not be interpreted.

Stimulus Protocol Selection

ABR protocols must align with the clinical question. Examples include:

- *High intensity clicks for neural integrity assessment*

- *Frequency specific tone bursts for threshold estimation*
- *Rate manipulation for stressing neural conduction*

Protocol selection should never be arbitrary.

Pediatric Specific Protocol Considerations

In infants and young children, protocols must account for:

- *Maturational latency differences*
- *Increased susceptibility to noise*
- *Limited test time due to sleep state*

Age appropriate norms and flexible protocols are essential.

Documentation of Recording Parameters

Accurate documentation is required for clinical interpretation and follow up. Reports should include:

- *Stimulus type and intensity*
- *Rate and polarity*
- *Filter settings*
- *Number of averages*
- *Patient state during testing*

Incomplete documentation undermines clinical and medico legal validity.

Clinical Implications

Proper recording parameters allow clinicians to:

- *Distinguish physiologic abnormality from technical artifact*
- *Optimize diagnostic sensitivity*
- *Ensure reproducibility across sessions and facilities*
- *Defend clinical conclusions with confidence*

Technical precision is inseparable from clinical accuracy.

– Clinical Summary

*This overview of **Auditory Brainstem Response (ABR)** measurement addresses the transition from simplistic anatomical models to our modern understanding of how the brainstem processes sound. It highlights the terminology, the "onset" nature of the response, and the complex neural generators involved.*

1. Waveform Terminology & Mnemonics

*The ABR consists of a series of peaks occurring within the first 10–15 ms after a sound. Jewett and Williston established the standard **Roman numeral (I–V)** labeling system.*

The "Rule of 5" Mnemonic

For high-intensity click stimulation (approx. 85 dB nHL) in a healthy adult:

- **Wave I:** Occurs at **~1.5 ms**.
- **Wave V:** Occurs at **~5.5 ms**.
- **Amplitude:** Wave V is roughly **0.5 μ V**.
- **Inter-wave Interval:** The I–V delay is roughly **4.0 ms** (Upper limit of normal is **4.5 ms**).
- **Interval Logic:** Each major wave (I, II, III, IV, V) appears at approximately **1.0 ms** intervals from the one before it.

Note: *These values increase (become "delayed") in infants under 18 months and when using low-frequency tone bursts or softer sounds.*

2. ABR as an "Onset Response"

The ABR is triggered by the synchronous firing of **onset neurons**, specifically **octopus cells** in the cochlear nucleus.

- Because only the "start" of a sound triggers this synchrony, very brief **Clicks** (0.1 ms) or short **Tone Bursts** are the most effective stimuli.
- Portions of a sound following the initial onset contribute almost nothing to the ABR waveform.

3. Modern Anatomical Generators

Early audiology used the "**ECOLI**" mnemonic (Eighth nerve, Cochlear nucleus, Olivary complex, Lateral lemniscus, Inferior colliculus) to suggest a simple 1-to-1 relationship between waves and structures. Modern human research shows a much more complex "multiple-generator" reality:

Wave	Primary Anatomical Generator(s)	Side of Brainstem
Wave I	Distal 8th Nerve (as it leaves the cochlea)	<i>Ipsilateral (Same side)</i>
Wave II	Proximal 8th Nerve (as it enters the brainstem)	<i>Ipsilateral</i>
Wave III	Cochlear Nucleus (Caudal Pons)	<i>Predominantly Ipsilateral</i>
Wave IV	Superior Olivary Complex / Lateral Lemniscus	<i>Bilateral / Parallel processing</i>
Wave V	Lateral Lemniscus (at the entry to the Inferior Colliculus)	Contralateral (Opposite side)

Table 19.1

Key Principle: Volume Conduction

The ABR waves are "far-field" potentials. They travel through brain tissue and fluids to reach the scalp electrodes via **volume conduction**.

- **Open Field:** Axons arranged in parallel (like the lateral lemniscus) create strong electrical fields that are easily detected.
- **Closed Field:** Complex structures with neurons firing in many directions (like parts of the Inferior Colliculus) can "cancel out" their own electrical signals, making them harder to see on the scalp.

4. Clinical Significance & Evolutions

- **The MRI Impact:** While ABR was once the primary tool for finding brain tumors (acoustic neuromas), MRI has largely taken over that role.
- **Current Power:** Today, ABR's primary strength lies in **Objective Pediatric Assessment** and diagnosing **Auditory Neuropathy (ANS)**.
- **FFR (Frequency Following Response):** A related response where the brainstem "mimics" the frequency of a continuous low-frequency tone. While less common clinically, it is a vital tool for research into music and speech perception.

Common Pitfalls

- Using default system settings without clinical justification
- Ignoring impedance imbalance
- Interpreting non replicated waveforms

- *Comparing results obtained with different protocols*

Red Flags

- *Latency shifts inconsistent with stimulus changes*
- *Interpretation without confirming recording quality*

Clinical Pearls

- *Documentation protects both patient and clinician*

Take-Home Messages

- *ABR results are highly dependent on recording parameters*
- *Proper patient preparation and impedance control are essential*
- *Filter settings and time windows influence waveform integrity*
- *Replication confirms true neural responses*
- *Thoughtful protocol selection ensures evidence based interpretation*



CHAPTER

20

*Auditory Brainstem Response**Stimulus Parameters*

*Before you see a waveform,
you already made decisions.*

Not clinical conclusions—

stimulus decisions.

In ABR, stimulus parameters are not technical preferences.

*They are **clinical assumptions.***

Change the stimulus,

and you change:

- *what part of the system responds*
- *how synchronized it fires*
- *what latency means*
- *and what conclusions become possible or dangerous*

ABR interpretation does not begin with Wave V.

It begins with the stimulus.

Why Stimulus Parameters Are the Hidden Engine of ABR

ABR looks objective.

Stimulus parameters make it subjective.

They decide:

- *which neural populations are activated*
- *how timing is interpreted*
- *whether absence means pathology—or design*

Many ABR “abnormalities” are not neural problems.

*They are **stimulus problems**.*

Stimulus Type: What Question Are You Asking?

Every stimulus asks a different question.

Click

Asks:

Is there synchronized neural firing in the high-frequency-dominant region?

- *Broad spectral content*
- *Strong synchrony*
- *Excellent for neurodiagnostic use*

But:

- *Poor frequency specificity*
- *when used to infer “overall hearing”*

Tone Burst

Asks:

How does the system respond at a specific frequency?

- *Better frequency specificity*

- *Less synchrony*
- *Requires patience and precision*

Chirp

Asks:

Can we improve synchrony by compensating for cochlear travel time?

- *Designed to enhance amplitude*
- *Alters latency interpretation*
- *Powerful—but interpretation must adapt*

Choosing the wrong stimulus

means answering the wrong question—accurately.

Stimulus Intensity: Visibility vs Meaning

High intensity:

- *improves waveform visibility*
- *reduces threshold relevance*

Low intensity:

- *challenges detection*
- *improves threshold estimation*

The mistake:

using high-intensity clarity

to justify low-intensity conclusions.

Visibility is not validity.

Stimulus Rate: Speed Always Has a Price

Faster rates:

- *shorten test time*
- *stress neural synchrony*

- *prolong latencies*
- *reduce amplitude*

Slower rates:

- *improve clarity*
- *increase confidence*
- *cost time*

Rate selection is a **physiological compromise**,
not a workflow decision.

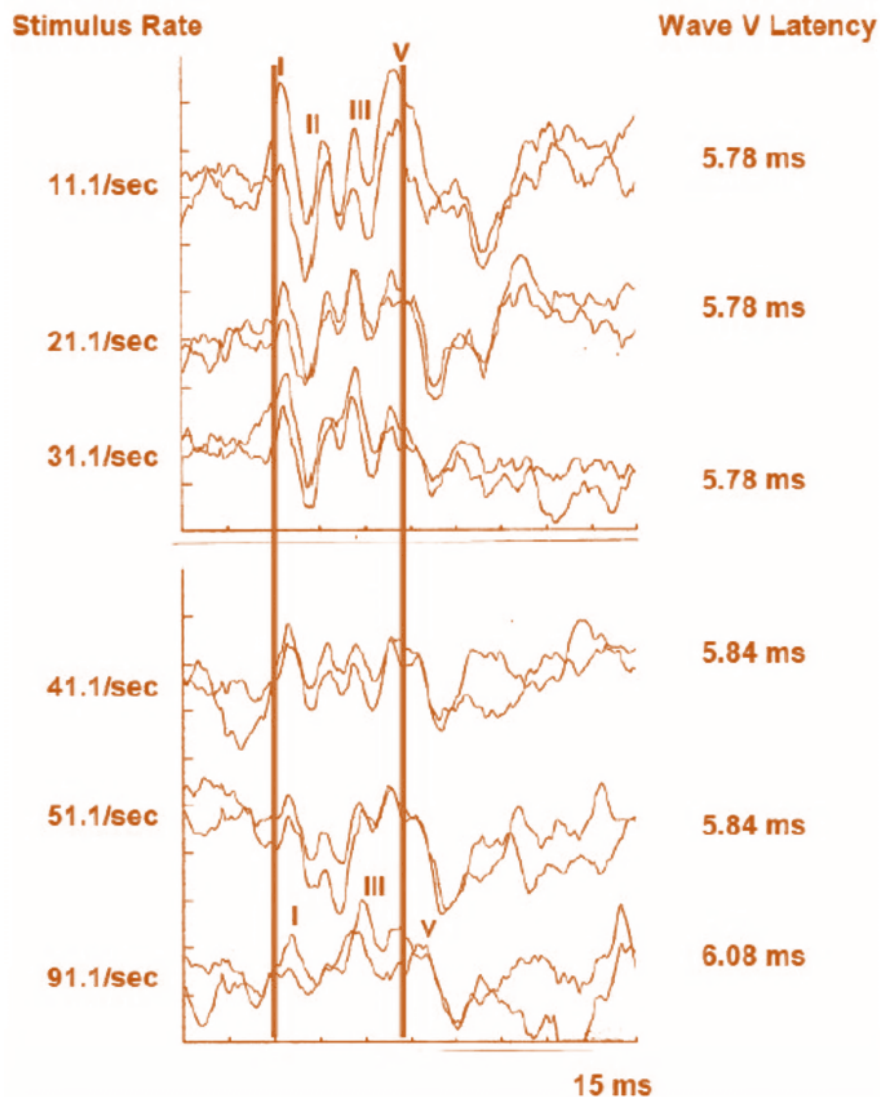


Figure 20.1 Effect of click stimulus presentation rate on ABR waveforms for a normal hearing adult subject

Polarity: What You Reveal—or Hide

Polarity is not cosmetic.

- ***Rarefaction / Condensation***

Reveal cochlear microphonic

Aid ANSD evaluation

- ***Alternating***

Reduces stimulus artifact

Can cancel important cochlear information

Polarity choices silently shape interpretation.

Envelope and Duration: The Shape of Sound Matters

Rise/fall times influence:

- *spectral splatter*
- *frequency specificity*
- *neural synchrony*

Sharper is not always better.

Shorter is not always cleaner.

ABR responds to physics

before it responds to pathology.

Default Stimulus Settings: Borrowed Judgment

Default settings reflect:

- *manufacturer assumptions*
- *average patients*
- *generic goals*

*They do **not** reflect:*

- *your patient*

- *your clinical question*
- *your responsibility*

Using defaults blindly

means outsourcing thinking.

Many ABR reports fail

before interpretation even begins.

Because stimulus parameters were chosen casually,

but interpreted confidently.

That mismatch creates harm.

– Clinical Summary

Understanding stimulus parameters is critical for obtaining reliable, interpretable ABR recordings. Small changes in stimulus delivery can significantly affect waveform morphology, latency, and diagnostic accuracy.

1. Transducers

The transducer determines how sound is delivered to the auditory system and directly influences latency values and calibration.

Commonly used transducers

- **Insert earphones** (ER-3A, ER-5A)
 - *Preferred in most clinical settings*
 - *Reduce ear canal collapse*
 - *Improve interaural attenuation*
 - *Minimize stimulus artifact*

- *Delay waveform latencies due to tubing length, this must be corrected using normative data*
- ***Supra-aural headphones***
 - *Shorter stimulus delay*
 - *Higher risk of ear canal collapse, especially in infants*
 - *Increased stimulus artifact*
- ***Bone conduction oscillator***
 - *Used to differentiate conductive versus sensorineural pathology*
 - *Limited maximum output*
 - *Requires careful masking of the non test ear*

Clinical note

Normative latency values are transducer specific and must never be interchanged.

2. Stimulus Types

The stimulus defines neural synchrony and frequency specificity.

Click

- *Broadband stimulus*
- *Activates primarily the 2 to 4 kHz region of the cochlea*
- *Excellent neural synchrony*
- *Ideal for neurological integrity and screening*

Tone burst

- *Frequency specific, commonly 500, 1000, 2000, and 4000 Hz*
- *Essential for threshold estimation*
- *Longer latencies compared to clicks*

- *Requires careful envelope shaping*

Chirp

- *Time compensated stimulus*
- *Aligns cochlear traveling wave delays*
- *Produces larger wave V amplitudes*
- *Useful for threshold estimation and screening*

3. Masking

Masking is required whenever there is a risk of cross hearing.

Indications

- *Asymmetric hearing loss*
- *Bone conduction ABR*
- *High intensity air conduction stimulation*

Type

- *Broadband noise, usually delivered to the non test ear*

Key principle

Masking levels must be sufficient to prevent crossover without overmasking, especially in infants and sedated patients.

4. Duration

Stimulus duration affects frequency specificity and neural synchrony.

Clicks

- *Very brief, typically 100 microseconds*

Tone bursts

- *Defined by rise, plateau, and fall times*
- *Longer durations increase frequency specificity*
- *Excessive duration reduces neural synchrony*

Clinical balance

Short enough to preserve synchrony, long enough to maintain frequency specificity.

5. Intensity

Intensity is usually expressed in dB nHL.

High intensity

- *Used for neurological assessment*
- *Enhances waveform morphology*
- *Increases stimulus artifact risk*

Low intensity

- *Used for threshold estimation*
- *Wave V persists closest to behavioral threshold*
- *Requires more averaging*

Important

Never equate ABR thresholds directly with behavioral thresholds without correction factors.

6. Rate of Stimulation

Stimulus rate influences neural adaptation and latency.

Slow rates

- *Better waveform morphology*
- *Longer test time*
- *Preferred for threshold estimation*

Fast rates

- *Stress the auditory pathway*
- *Reveal retrocochlear pathology*

- *Increase wave V latency and reduce amplitude*

Typical ranges

- *11 to 21 stimuli per second for routine testing*
- *Faster rates for neurological investigation*

7. Polarity

Polarity affects cochlear microphonic and stimulus artifact.

Rarefaction

- *Earlier wave I latency*
- *Enhances cochlear microphonic*

Condensation

- *Slightly delayed wave I*
- *Useful for comparison*

Alternating

- *Cancels cochlear microphonic*
- *Reduces stimulus artifact*
- *Preferred for neurological ABR*

8. Binaural Stimulation

Binaural stimulation evaluates brainstem interaction.

Uses

- *Assessment of binaural processing*
- *Research applications*
- *Comparison with monaural responses*

Clinical limitation

Limited diagnostic use in routine ABR, monaural stimulation remains standard.

Concluding Comments

ABR stimulus parameters are not technical details, they are clinical decisions. Each parameter must be selected intentionally based on the test objective, whether neurological assessment, threshold estimation, or differential diagnosis.

Key Points

- *Intensity, rate, and polarity directly affect interpretation.*

Common Mistakes

- *Using click ABR to infer frequency-specific hearing.*
- *Using fast rates to save time without acknowledging effects.*
- *Ignoring polarity in suspected ANSD.*

Red Flags

- *Threshold claims from non-frequency-specific stimuli.*
- *Latency interpretation without considering rate or chirp effects.*

Pitfalls

- *Confusing robustness with accuracy*
- *Letting speed dictate stimulus choice*
- *Forgetting physics precedes physiology*

Ethics

- *Stimulus choice affects life decisions.*

Documentation

- *Record stimulus type, intensity, rate, and polarity.*



CHAPTER

21

*Auditory Brainstem Response**Stimulus Parameters: Transducers*

*Before sound reaches the ear,
before the cochlea vibrates,
before neurons synchronize—
it passes through a **transducer**.*

In ABR, the transducer is not a delivery device.

*It is a **physiological filter**.*

*Change the transducer,
and you change:*

- *stimulus timing*
- *stimulus spectrum*
- *stimulus intensity at the cochlea*
- *and sometimes... the diagnosis itself*

Many ABR errors are not waveform errors.

*They are **transducer errors** disguised as neural findings.*

Why Transducers Matter More Than You Think

ABR measures time with millisecond precision.

Transducers introduce:

- *acoustic delay*
- *frequency shaping*
- *coupling variability*

*If you ignore the transducer,
your latency interpretation starts already wrong.*

*You are measuring the brain
with a stopwatch that started late.*

Insert Earphones: Precision with Responsibility

Insert earphones are widely used—and often preferred.

What They Do Well

- *Reduce ear canal collapse*
- *Improve interaural attenuation*
- *Minimize stimulus artifact*
- *Enhance waveform clarity*

What They Change

- *Introduce tubing delay*
- *Shift absolute latencies*
- *Modify effective stimulus spectrum*

*Latency norms without transducer correction
are scientifically invalid.*



Figure 21.1A. Insert earphones placement on an infant boy 4 weeks after term birth. Notice the distance between the transducer for the insert earphones and the electrode box and electrode wires. Photograph courtesy of William-James Finn McNeal and Victoria Hall-McNeal.



Figure 21.1B. Insert earphones placement on a 2.5-year old boy. Notice the distance between the transducer for the insert earphones and the electrode box and electrode wires. Photograph courtesy of Austin “Charlie” Hall, Austin Hall, and Alessandra Muñoz-Hall.

Supra-Aural Headphones: Familiar but Risky

Supra-aural headphones feel simple.

They are not.

Limitations

- *Increased stimulus artifact*
- *Greater risk of ear canal collapse (especially in infants)*
- *Less interaural attenuation*

Using supra-aural transducers in ABR requires heightened caution—especially in pediatrics.

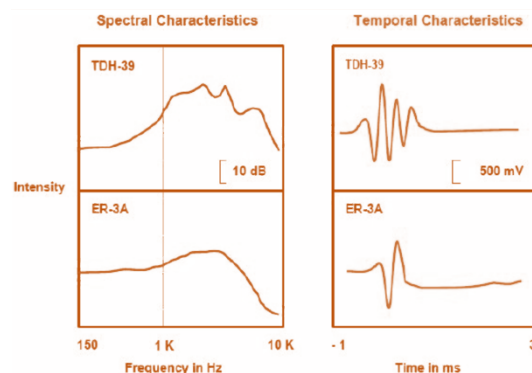


Figure 21.2. Spectral and temporal characteristics of supra-aural earphones (TDH-39) and insert earphones (ER-3A)

Bone Conduction Transducers: Powerful and Dangerous

Bone conduction ABR is not a backup test.

*It is a **different physiological experiment.***

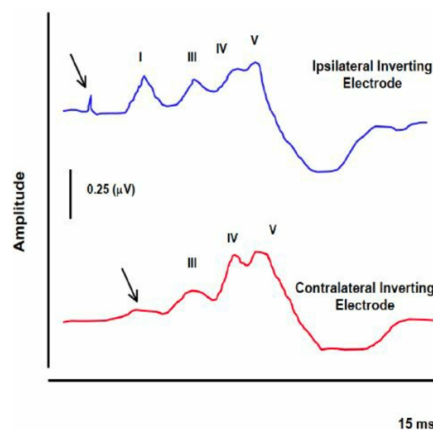


Figure 21.3 ABR waveforms evoked with bone conduction stimulation recorded with ipsilateral and contralateral electrode array. The arrow in the waveform with an inverting electrode on the earlobe of the stimulus ear (ipsilateral waveform) points to stimulus artifact.

The arrow in the waveform with an inverting electrode on the earlobe of the non-test ear (contralateral waveform) points to the latency region where wave I is found in the ipsilateral waveform.

What BC ABR Can Do

- Differentiate conductive vs sensorineural components
- Support cross-check principles

What It Cannot Do Reliably

- *Provide precise threshold estimates*
- *Avoid contralateral stimulation without masking*

BC transducers introduce:

- *distortion*
- *vibrotactile responses*
- *complex skull transmission*

Interpretation without restraint becomes speculation.

Calibration: The Invisible Assumption

ABR interpretation assumes:

What you think you presented is what reached the cochlea.

That assumption is fragile.

Calibration depends on:

- *transducer type*
- *tubing length*
- *coupler vs real-ear differences*
- *age and ear canal volume*

Unverified calibration

creates beautiful but meaningless data.

Transducer Delay: The Silent Latency Trap

Every transducer has delay.

Insert earphones delay sound more than supra-aural ones.

If not corrected:

- *absolute latencies appear prolonged*
- *inter-lab comparisons become invalid*
- *pathology is falsely suspected*

This is one of the **most common hidden errors** in ABR reporting.

Transducer Choice Is a Clinical Decision

Choosing a transducer answers questions like:

- Do I prioritize artifact reduction or timing accuracy?
- Am I testing neural integrity or estimating thresholds?
- Is this an infant, adult, or special population?

Transducer choice is not preference.

It is **intentional design**.



Figure 21.1. Insertphone.

– Clinical Summary

Transducers are the interface between the stimulus generator and the auditory system. In ABR measurement, the choice of transducer directly affects stimulus delivery, calibration accuracy, waveform morphology, latency values, artifact level, and ultimately diagnostic reliability.

No single transducer is optimal for all patients or all clinical applications. Selection must be individualized based on patient age, test objective, test environment, and clinical constraints.

The three transducers most commonly used in clinical ABR recordings are:

- *Insert earphones*
- *Supra-aural earphones*
- *Bone vibrators or oscillators*

Loudspeakers are rarely used for ABR and are primarily reserved for cortical auditory evoked responses

Insert Earphones

General Considerations

*Insert earphones are the **transducer of choice for ABR**, particularly in infants and young children. Extensive clinical experience and research support their routine use in pediatric populations.*

Clinical Advantages

Insert earphones offer multiple advantages over conventional supra-aural earphones:

- ***Increased interaural attenuation***, significantly reducing stimulus crossover and decreasing the need for masking during air conduction ABR
- ***Improved ambient noise reduction***, a critical advantage when testing in hospital rooms, nurseries, operating rooms, or imaging suites
- ***Reduced risk of ear canal collapse***, especially important in infants with soft cartilaginous pinnae
- ***Improved patient comfort***, facilitating testing in quiet awake or natural sleep states

- **More precise stimulus placement** within the external auditory canal, improving threshold estimation accuracy
- **Flutter frequency response** compared to supra-aural earphones
- **Reduced transducer ringing**, resulting in cleaner temporal waveforms
- **Marked reduction in stimulus artifact**, due to physical separation of the transducer from electrodes and electrode wires
- **Improved infection control**, as disposable insert tips allow single patient use
- **Compatibility with sterile conditions**, including gas sterilization for intraoperative monitoring
- **Option for TIP trode use**, which can significantly enhance Wave I amplitude, particularly valuable in suspected auditory neuropathy spectrum disorder (ANSD).

Calibration and Infant Ear Canal Considerations

Concerns have been raised regarding the use of insert earphones in newborns due to smaller ear canal volumes, which may lead to higher sound pressure levels compared to adults. Reports suggest potential increases of approximately 10 to 20 dB SPL in infant ear canals, with variability across frequency and study methodology.

Two theoretical concerns are commonly discussed:

- 1 Risk of excessive sound exposure at high stimulus intensities
- 2 Potential overestimation of hearing sensitivity near threshold levels

However, despite decades of widespread clinical use, there is **no convincing clinical or research evidence** demonstrating systematic

underestimation of hearing loss or harm to infant hearing due to insert earphone use in ABR testing.

Prudent clinical practice further mitigates risk:

- *Testing typically begins at moderate to high intensities and decreases if a response is present*
- *Maximum stimulus levels are usually reached only when hearing loss is suspected*
- *The diagnostic benefit of early and accurate threshold estimation far outweighs theoretical risks.*

Supra-Aural Earphones

Historical Perspective

Prior to the 1990s, supra-aural earphones such as the TDH-39 mounted in MX41/AR cushions were routinely used in ABR testing. Their use was driven primarily by availability and existing audiometric standards rather than suitability for infant testing.

Limitations in ABR Recording

Supra-aural earphones present multiple disadvantages in ABR measurement, particularly in newborns and infants:

- *Inconsistent placement on small pinnae*
- *Risk of external ear canal collapse due to pressure*
- *Poor infection control due to non-disposable cushions*
- *Inferior temporal and spectral stimulus characteristics*
- *Increased stimulus artifact at high intensity levels*
- *Greater susceptibility to ambient noise*

High newborn screening failure rates in earlier decades were attributed in part to inconsistent supra-aural earphone placement.

Current Clinical Role

While supra-aural earphones can technically deliver adequate stimulus levels, there is little rationale for their continued routine use in ABR when insert earphones are available and properly calibrated.

Bone Vibrators (Bone Conduction ABR)

Purpose

Bone conduction ABR is used to differentiate conductive from sensorineural hearing loss by bypassing the external and middle ear.

Technical Considerations

- *Bone vibrator output decreases at higher frequencies, particularly above 2000 Hz*
- *Maximum effective stimulus levels typically range from 50 to 55 dB nHL*
- *Dial or screen intensity does not correspond directly to air conduction reference levels*
- *Effective stimulation at higher frequencies remains clinically useful despite reduced force output*

Clinical Implications

Bone conduction ABR requires:

- *Careful placement and coupling force*
- *Mandatory masking of the non test ear*
- *Conservative interpretation due to output limitations.*

Clinical Take Home Message

Transducer selection in ABR is not a technical afterthought, it is a core clinical decision. Insert earphones provide superior stimulus control, artifact reduction, patient comfort, and diagnostic reliability, particularly in infants and young children. Supra-aural earphones are largely obsolete for routine ABR, and bone vibrators remain essential for differential diagnosis when used with appropriate caution and masking.

Key Points

- *Transducers shape stimulus timing and spectrum.*
- *Insert earphones introduce delay that must be corrected.*
- *Supra-aural and bone conduction transducers have specific risks.*
- *Calibration is essential for valid interpretation.*

Common Mistakes

- *Using adult latency norms with insert earphones without correction.*
- *Ignoring transducer-specific calibration.*
- *Treating BC ABR as equivalent to air-conduction ABR.*
- *Failing to document transducer type.*

Ethics

- *Transducer-related errors mislead life-altering decisions.*



CHAPTER

22

*Auditory Brainstem Response**Stimulus Parameters: Stimulus Types*

ABR does not respond to “sound.”

*It responds to **a specific stimulus design.***

Every stimulus type is a question.

And every question limits the answer.

*If you misunderstand the stimulus,
you will misunderstand the ABR—
even if the waveform is perfect.*

Why Stimulus Type Is the Most Decision in ABR

Stimulus type decides:

- *which cochlear regions dominate the response*
- *how synchronized neural firing becomes*
- *what latency means*
- *and what conclusions are even allowed*

Most ABR misinterpretations are not reading errors.

*They are **question-design errors.***

You asked the wrong question very well.

Click Stimulus: Power with a Price

What the Click Really Is

A click is:

- *broadband*
- *extremely brief*
- *spectrally biased toward high frequencies*

*It does **not** stimulate the cochlea evenly.*

What the Click Is Good For

- *Neural synchrony*
- *Neurodiagnostic ABR*
- *Waveform morphology*
- *Latency and interpeak analysis*

What the Click Is NOT

- *A frequency-specific hearing test*
- *A guarantee of “normal hearing”*
- *A full representation of the audiogram*

Click ABR answers:

Is the auditory pathway capable of synchronized firing—primarily in the high-frequency region?

Nothing more.

Tone Burst Stimuli: Precision Requires Humility

What Tone Bursts Attempt

Tone bursts try to ask:

How does the system respond at a specific frequency?

They trade synchrony for specificity.

Strengths

- *Better frequency targeting*
- *More meaningful threshold estimation*
- *Critical for fitting and intervention planning*

Limitations

- *Smaller amplitudes*
- *Less robust waveforms*
- *Greater susceptibility to noise and interpretation bias*

Tone-burst ABR is not weak.

*It is **honest**.*

Chirp Stimuli: Engineering Meets Physiology

Why Chirps Exist

The cochlea does not respond simultaneously across frequencies.

Chirps attempt to:

- *compensate for cochlear travel time*
- *align neural firing*
- *increase response amplitude*

What Chirps Change

- *Waveform morphology*
- *Latency interpretation*
- *Normative comparisons*

A chirp is not a better click.

*It is a **different stimulus with different rules**.*

*Using chirp norms on click thinking
is a classic modern mistake.*

Stimulus Bandwidth: What You Include—What You Exclude

Broad stimuli:

- *enhance synchrony*
- *reduce specificity*

Narrow stimuli:

- *improve frequency relevance*
- *challenge detectability*

Bandwidth is a clinical compromise—not a technical setting.

Polarity Interaction with Stimulus Type

Stimulus type interacts with polarity.

- *Click + alternating polarity*
→ *cleaner waveform, less CM visibility*
- *Click + single polarity*
→ *better CM detection, more artifact*

*Stimulus choice without polarity awareness
is incomplete design.*

Why “One Stimulus Fits All” Is a Myth

No stimulus answers all questions.

- *Click $\neq$ threshold*
- *Tone burst $\neq$ neurodiagnosis*
- *Chirp $\neq$ universal improvement*

*The more confidently a clinician uses one stimulus for everything,
the more likely they misunderstand ABR.*

Clinical Decision-Making

- *What question did this stimulus ask?*
- *What questions did it ignore?*
- *Would a different stimulus change management?*

*Stimulus selection is central to the clinical utility of the Auditory Brainstem Response. Unlike other auditory evoked responses where the focus may be primarily on response morphology, ABR measurement, particularly in infants and young children, places critical emphasis on stimulus properties, especially **frequency content and intensity**. In pediatric populations, the ABR waveform is not the goal in itself, but rather a tool for **accurate estimation of auditory thresholds** across frequencies important for speech perception and language development.*

The ultimate objectives of diagnostic ABR assessment in infants include:

- *Confirmation or exclusion of hearing loss*
- *Guidance for early amplification or cochlear implantation*

Accurate stimulus selection and quantification directly influence a child's speech and language outcomes and quality of life.

Stimuli used to evoke the ABR include:

- *Clicks*
- *Tone bursts*
- *Chirp versions of clicks and tone bursts*
- *Less commonly, speech and experimental stimuli*

Click Stimuli

Physiologic Basis

Conventional click stimuli have an extremely brief duration, typically around 0.1 ms, producing highly synchronous neural firing beginning at the auditory nerve. Due to the inverse relationship between stimulus duration and spectral bandwidth, clicks are inherently broadband stimuli, activating the cochlea from base to apex.

*However, the resulting ABR is **dominated by activity from the basal, high-frequency regions** of the cochlea due to:*

- *Faster traveling wave velocity in the basal region*
- *Greater neural synchrony in high-frequency cochlear regions*
- *Temporal dispersion of neural firing toward the apex*

As a result, click-evoked ABRs in normal hearing listeners primarily reflect cochlear regions corresponding approximately to 2000–4000 Hz, despite the broadband nature of the stimulus.

Clinical Implications

- *Click-evoked ABR thresholds correlate best with behavioral thresholds in the 2000–4000 Hz region*
- *Latency prolongation may reflect hearing loss in basal regions, with responses generated from more apical regions*
- *Different cochlear regions may contribute differently to wave I versus wave V generation*
- *At high stimulus levels, spread of excitation toward apical regions increases*

Click stimuli are highly effective for:

- *Screening neural integrity*

- *Assessing retrocochlear pathology*
- *Providing a rapid overview of auditory function*

However, click-evoked ABRs **lack sufficient frequency specificity** for comprehensive threshold estimation, especially in pediatric hearing assessment.

Chirp Click Stimuli

Rationale

Chirp stimuli were developed to overcome the inherent temporal dispersion associated with click stimulation. A chirp stimulus compensates for cochlear traveling wave delay by presenting **low-frequency energy earlier** and **high-frequency energy later**, such that activity from different cochlear regions arrives at the brainstem simultaneously.

The physiologic goal is synchronized activation from base to apex, resulting in:

- *Larger ABR wave V amplitudes*
- *Improved signal-to-noise ratio*
- *More reliable detection near threshold*
- *Reduced test time*

Clinical Advantages

Extensive research confirms that chirp-evoked ABRs, particularly at low-to-moderate intensity levels, produce:

- *Wave V amplitudes often doubled compared to conventional clicks*
- *Earlier and more robust responses*

- *Improved threshold estimation accuracy in infants and young children.*

Level-Specific Chirps

Fixed chirps designed for low intensity stimulation may lose effectiveness at high intensity levels. Level-specific (LS) chirps address this limitation by adjusting chirp duration based on stimulus intensity, optimizing synchronization across cochlear regions at each level.

LS-chirps:

- *Maintain large wave V amplitudes across a wide intensity range*
- *Are calibrated using international ISO standards*
- *Represent a major advance in clinical ABR measurement*

Not all chirps are equivalent. Clinical use should be limited to chirp stimuli with clear theoretical justification and published clinical validation.

Bone Conduction Click Stimulation

Clinical Role

Bone conduction ABR is an essential component of pediatric diagnostic assessment when middle ear dysfunction is suspected. It allows differentiation between:

- *Conductive hearing loss*
- *Sensorineural hearing loss*
- *Mixed hearing loss*

Bone conduction ABR has been validated extensively in infants and young children, even in the neonatal period.

Technical Considerations

- *Maximum effective intensity is typically limited to 50–55 dB nHL*
- *Effective stimulus level varies with vibrator placement and coupling force*
- *Latency differences between air and bone conduction are influenced by age, placement, and stimulus spectrum*
- *Temporal bone placement generally yields the most robust responses*

*Importantly, interaural attenuation for bone conduction is **greater in neonates** than in adults due to incomplete skull fusion, improving ear specificity in infants.*

Masking Considerations

The traditional masking dilemma of behavioral audiometry is largely mitigated in ABR. Identification of a clear ipsilateral wave I confirms test ear activation, reducing the need for contralateral masking in many clinical scenarios.

Frequency-Specific ABR and Tone Burst Stimuli

Need for Frequency Specificity

Click-evoked ABRs alone are insufficient for accurate assessment of hearing sensitivity relevant to speech and language. Significant hearing losses may be missed or mischaracterized if frequency-specific stimuli are not used.

Tone burst ABRs allow estimation of auditory thresholds across discrete frequency regions critical for speech perception, typically:

- *500 Hz*

- 1000 Hz
- 2000 Hz
- 4000 Hz

Clinical Status

Tone burst ABR is now considered **standard of care** in pediatric audiology and is strongly endorsed by international guidelines, including the Joint Committee on Infant Hearing.

With appropriate stimulus shaping and acquisition parameters:

- *Thresholds are typically within 10 dB of behavioral thresholds*
- *Over 90 percent of cases fall within ± 20 dB*
- *Reliability is highest when combined with crosscheck measures such as OAEs and immittance*

Chirp Tone Burst Stimuli

Chirp versions of tone bursts apply the same temporal compensation principles to octave-band stimuli. Compared to conventional tone bursts, chirp tone bursts produce:

- *Shorter latencies*
- *Larger wave V amplitudes*
- *Improved detectability near threshold*
- *Reduced test time*

These advantages are well documented and increasingly adopted in clinical practice.

Speech and Experimental Stimuli

Speech-evoked ABRs and frequency-following responses provide insight into neural encoding of speech but are primarily used for

research and auditory processing studies rather than routine threshold estimation.

Other experimental stimuli, including paired clicks, filtered clicks, offset responses, and modulated tones, have been explored but remain limited in routine clinical application due to variability, complexity, or limited diagnostic yield

Clinical Take Home Message

*Stimulus selection in ABR measurement is a **clinical decision with lifelong consequences**. Clicks provide rapid assessment of neural synchrony but lack frequency specificity. Tone bursts and chirp stimuli are essential for accurate threshold estimation in infants and young children. Bone conduction stimulation completes the diagnostic picture by differentiating types of hearing loss. Mastery of stimulus properties is fundamental to evidence-based, ethical, and effective pediatric audiology.*

Ethics

- *Using the wrong stimulus misleads decisions.*

Documentation

- *Specify stimulus type, bandwidth, and rationale.*

Report Writing

- *Avoid global hearing statements from narrow stimuli.*
- *Write for future reviewers—not just current decisions.*



CHAPTER

23

Auditory Brainstem Response
Stimulus Parameters: Masking



Masking in ABR is not optional.

*It is **ethical containment**.*

*ABR measures neural timing with millisecond precision,
but the auditory system listens with **two ears**,
and the skull does not respect your test plan.*

*If you ignore masking,
you may be recording the **wrong ear perfectly**.*

Why Masking Is More Critical in ABR Than You Think

ABR feels objective.

Masking feels behavioral.

That illusion is dangerous.

In ABR:

- *cross-hearing happens silently*
- *the waveform looks clean*
- *the error hides in plain sight*

*Masking is the only barrier
between a valid interpretation
and a confident mistake.*

The Physics You Cannot Negotiate

Sound crosses the skull.

Interaural attenuation is:

- *limited*
- *transducer-dependent*
- *frequency-dependent*

*If the stimulus reaches the non-test ear at an effective level,
the ABR will not tell you which ear responded.*

It will just respond.

When Masking Is Required

Masking is required whenever:

- *there is significant asymmetry*
- *bone conduction ABR is performed*
- *air-conduction ABR levels exceed interaural attenuation*
- *thresholds are estimated in unilateral or asymmetric loss*

*If you are unsure—
mask.*

Silence is cheaper than correction.

Masking in Air-Conduction ABR

With air-conduction:

- *insert earphones increase interaural attenuation*
- *supra-aural headphones reduce it*

High-intensity stimuli can still cross.

Failure to mask may result in:

- *false-normal responses*
- *misattributed thresholds*
- *delayed diagnosis*

*A clean waveform from the wrong ear
is still wrong.*

Masking in Bone-Conduction ABR: No Exceptions

*Bone conduction ABR **always stimulates both cochleae.***

There is no “test ear” without masking.

Without masking:

- *side-specific conclusions are invalid*
- *conductive vs sensorineural distinctions collapse*

BC ABR without masking

is documentation—not diagnosis.

Masking Noise: What and How

Effective masking requires:

- *appropriate noise type*
- *adequate level*
- *stability throughout recording*

Under-masking:

- *fails silently*

Over-masking:

- *suppresses the test response*

*Masking is a **balance**, not a number.*

Why Clinicians Avoid Masking—and Why They Shouldn't

Masking takes time.

Masking complicates setup.

Masking introduces uncertainty.

Avoiding masking feels efficient.

But efficiency that creates wrong answers

is negligence wearing a lab coat.

Masking is defined by the ANSI standard on Acoustical Terminology as “the amount by which the threshold of audibility of a sound is raised by the presence of another (masking) sound.” In auditory evoked response measurement, contralateral masking refers to the presentation of noise to the non-test ear to prevent it from contributing to the recorded response when such contribution is possible or likely .

Masking noise is characterized by two essential properties:

- ***Effective intensity level***, expressed in dB
- ***Spectral content***, which must be appropriate for the stimulus being masked

The frequency response of the transducer, whether an earphone or a bone oscillator, limits the effective frequency range of both the stimulus and the masking noise. For ABR measurement:

- ***Broadband noise (BBN)*** is most appropriate for masking click stimuli
- ***Narrowband noise*** is more effective for masking tone burst stimuli when frequency specificity is required .

Contralateral Masking in ABR Measurement

Key Clinical Questions

At least seven clinically relevant questions guide decisions about masking in ABR:

- 1. Is masking ever necessary?*
- 2. Under what stimulus conditions is masking indicated?*
- 3. How should masking be delivered?*
- 4. What type of masking noise is most appropriate?*
- 5. How much masking is sufficient?*
- 6. Does masking noise itself influence auditory evoked responses?*
- 7. Can masking ever be counterproductive?*

Masking Is Not Always Required

*Masking is **rarely required** in routine ABR measurement. With insert earphones, interaural attenuation for air-conduction stimuli generally exceeds 60 dB, substantially reducing the likelihood of stimulus crossover at clinically relevant intensity levels. Supra-aural earphones provide less interaural attenuation but are not recommended for routine ABR testing .*

*For bone conduction stimulation, interaural attenuation is conservatively estimated as 0 dB HL, meaning that energy can theoretically reach both cochleae. Even so, masking is generally **not required** for bone-conduction ABR. This apparent contradiction is explained by fundamental differences between electrophysiological and behavioral responses.*

Why Masking Rules Differ for ABR and Behavioral Audiometry

Unlike behavioral responses, ABRs are **highly time-dependent**. When a stimulus crosses over from the test ear to the non-test ear:

- The effective intensity reaching the non-test ear is reduced by interaural attenuation
- Additional **latency delay** occurs due to stimulus transmission time
- The resulting ABR, if present, is **abnormally delayed**

In behavioral audiometry, only intensity matters. In ABR, both **intensity and timing** are critical. Delays on the order of milliseconds are negligible behaviorally but diagnostically decisive for short-latency responses such as the ABR .

Worst-Case Crossover Scenario Explained

Consider a worst-case clinical scenario:

- Profound hearing loss in the test ear
- Normal hearing and normal ABR in the non-test ear
- Click stimulus presented at 95 dB nHL

With insert earphones, approximately 65 dB of interaural attenuation is expected. The stimulus reaching the non-test ear would therefore be no greater than about 30 dB HL. At most, only a **delayed wave V** might be recorded, corresponding to low-level stimulation, and further delayed by crossover transit time. Such a response would be clearly abnormal and easily distinguished from a true response originating in the test ear .

The Role of Wave I in Identifying Crossover

*An ABR generated by crossover stimulation lacks a **wave I component** when the inverting electrode is placed near the test ear. A normal ABR with expected latencies for all wave components **cannot** originate from crossover stimulation. Therefore:*

- Presence of wave I supports test-ear origin*
- Markedly delayed wave V without wave I raises suspicion of crossover*

This principle substantially reduces the need for routine masking in ABR measurement .

When Masking Is Indicated

Masking becomes clinically necessary under specific conditions:

- Acoustic stimulation of a **profoundly impaired ear***
- **High stimulus intensity levels**, typically exceeding 75 to 80 dB nHL*
- Presence of a **markedly delayed wave V** that could represent either pathology or crossover*

Failure to recognize a crossover response may lead to underestimation of hearing loss in the poorer ear. In such cases, appropriate contralateral masking should be applied to confirm test-ear specificity .

Does Masking Affect Central Auditory Responses?

In behavioral audiometry, central masking refers to elevation of threshold in one ear due to noise presented to the contralateral ear, without physical crossover. Because central masking is mediated in

caudal brainstem structures, it is reasonable to question whether contralateral masking might alter ABR findings.

Experimental evidence indicates that **contralateral masking at low-to-moderate intensity levels (below approximately 70 dB HL)** does **not** produce consistent changes in ABR latency or amplitude. Thus, masking noise itself does not meaningfully distort ABR recordings when applied appropriately .

Clinical Take-Home Message

Masking in ABR measurement is the exception, not the rule. Insert earphones, time-dependent waveform analysis, and identification of wave I greatly reduce the likelihood of misinterpreting crossover responses. Masking is reserved for high-intensity stimulation of severely impaired ears when crossover cannot otherwise be excluded. When applied judiciously, contralateral masking does not distort ABR findings and serves as a safeguard against diagnostic error.

Common Mistakes

- *Performing BC ABR without contralateral masking.*

Ethics

- *Masking protects patients from misdiagnosis.*

Documentation

- *Document noise type, level, and rationale.*



CHAPTER

24

*Auditory Brainstem Response**Stimulus Parameters: Duration, Intensity, and Rate of Stimulation*

In ABR, nothing is neutral.

*Duration decides **how the sound enters the cochlea.***

*Intensity decides **who responds.***

*Rate decides **who survives the stress.***

These three parameters do not decorate the stimulus.

*They **reshape the physiology** you are trying to measure.*

Change them,

and the ABR tells a different story—

with the same brainstem.

Stimulus Duration: When Time Shapes Frequency

Duration is not just length.

*It is **spectral control.***

Short Duration

- *Broad spectral splatter*
- *Strong neural synchrony*

- *Better waveform visibility*

But:

- *Poor frequency specificity*
- *Risk of misleading “normality”*

Longer Duration

- *Improved frequency specificity*
- *Reduced spectral spread*

But:

- *Less synchrony*
- *Smaller amplitudes*
- *Greater vulnerability to noise*

Duration is a trade-off:

Synchrony vs specificity

*Choosing duration without intent
means choosing distortion politely.*

Duration of the Stimulus

Click Stimuli

*The Auditory Brainstem Response depends fundamentally on **synchronous neural firing**, which in turn requires an abrupt stimulus onset. For this reason, ABR is largely an **onset response**, and is relatively insensitive to stimulus duration itself.*

Two practical consequences follow:

1. *ABR morphology and latency are minimally affected by stimulus duration*
2. *Extremely brief click durations are sufficient and preferred*

*In clinical practice, the standard click duration is **0.1 ms (100 µsec)**. Durations as short as 20 µsec and as long as 400 µsec have been reported, but differences in ABR latency and amplitude across this range are small and clinically modest .*

Across durations from approximately 25 to 100 µsec, no meaningful latency change is observed. Increasing duration beyond 100 µsec results in only slight latency prolongation, generally no more than 0.2 ms even at 400 µsec. These changes are attributed not to duration itself, but to recovery processes and alterations in spectral energy distribution.

Clinical implication

*Click duration does not materially influence ABR latency or amplitude within typical clinical ranges. However, duration should always be **specified and held constant**, as it interacts with spectral content and maximum achievable intensity.*

Tone Burst Stimuli

*Tone burst duration is defined in terms of **cycles**, not milliseconds, to maintain equivalent energy across frequencies.*

The most widely used paradigms are:

- **2–1–2 cycles** (rise–plateau–fall)
- **2–0–2 cycles**, now commonly preferred

Research shows that the plateau portion contributes little to frequency specificity or ABR quality. Eliminating the plateau may reduce spectral splatter and improve stimulus efficiency .

Because duration in milliseconds varies inversely with frequency, low-frequency tone bursts have longer temporal durations than high-frequency tone bursts even when cycle counts are identical.

Rise Time and Neural Synchrony

ABR latency increases as stimulus rise time lengthens. This effect reflects reduced neural synchrony and increased contribution from apical cochlear regions. Identification of early waves, especially wave I, becomes difficult when rise time exceeds approximately 5 ms.

For low-frequency stimuli, especially 500 Hz, longer rise times may be required to preserve frequency specificity, but this comes at the expense of response clarity. Brief rise times optimize synchrony but increase spectral spread.

*A clinically effective compromise is achieved using **brief, well-shaped envelopes**, particularly when combined with appropriate gating.*

Tone Burst Envelopes

The stimulus envelope describes how amplitude rises and falls.

Envelope shape directly affects spectral side lobes and therefore frequency specificity.

*Early ABR work relied heavily on **linearly gated** tone bursts. These stimuli, however, have theoretical limitations, particularly at low frequencies, where spread of excitation may lead to underestimation of hearing loss.*

***Non-linear envelope shaping**, especially **Blackman windowing**, reduces side lobes while maintaining acceptable temporal characteristics. Although theoretical advantages are clear, empirical*

differences between linear and Blackman-gated stimuli in predicting behavioral thresholds are often modest, typically within 10–15 dB. Blackman-gated tone bursts remain an excellent and widely accepted option for pediatric threshold estimation .

Intensity of Stimulation

Clinical Importance

Stimulus intensity is the most frequently manipulated parameter in ABR testing and is central to both waveform quality and threshold estimation. During a single pediatric ABR assessment, intensity may be adjusted dozens of times to optimize response detection.

Latency decreases and amplitude increases as stimulus intensity increases. These relationships are predictable and form the foundation of ABR interpretation.

Calibration of Intensity

Calibration of transient stimuli is inherently more complex than calibration of pure tones. Current standards define intensity using **peRETSPL** and express stimulus levels in **dB nHL**, based on peak-equivalent SPL comparisons with a 1000 Hz reference tone.

Calibration involves three levels:

1. **Physical calibration**, typically performed by manufacturers
2. **Biological verification**, using normal-hearing adults in the actual test environment
3. **Clinical correction**, accounting for ambient noise and test location differences

Biological verification defines what the system's displayed 0 dB nHL actually represents in the real clinical setting. Correction factors may be required, especially in noisy environments such as NICUs or operating rooms .

Accurate stimulus calibration is the foundation for valid estimation of electrophysiologic thresholds and subsequent clinical decisions regarding amplification or implantation.

Effects of Intensity on ABR

Latency–Intensity Function

Wave V latency decreases systematically with increasing intensity. The latency–intensity function is nonlinear, with the steepest slope between threshold and approximately 60 dB nHL.

- *Near threshold, wave V latency is approximately 7.5–8.0 ms*
- *At high intensities (75–95 dB nHL), latency stabilizes around 5.5–6.0 ms*

Latency decreases rapidly at low-to-moderate intensities and much more gradually at high intensities. Overall, latency changes approximately 0.38 ms per 10 dB across the full intensity range .

Amplitude Effects

Wave V amplitude increases steadily with intensity, whereas wave I amplitude increases more rapidly at high intensities but decreases more sharply at low intensities. At moderate levels, wave V is typically the most robust and last remaining identifiable component.

Amplitude changes are more variable across subjects than latency changes and are more sensitive to noise and recording conditions.

Physiologic Basis

Multiple mechanisms contribute to intensity effects:

- *Basal shift of cochlear excitation at higher intensities*
- *Faster generator potentials and synaptic excitation*
- *Recruitment of broader neural populations*

*ABR contains both **slow and fast components**. The slow component saturates at moderate intensities, whereas fast components (waves I–V) continue to grow with intensity. Near threshold, response detection relies heavily on the slow component.*

Rate of Stimulation

General Principle

*Stimulus rate should be **as fast as possible while preserving waveform integrity**. Faster rates reduce test time and improve feasibility in infants and young children.*

Manufacturer default rates are not always optimal and should be reviewed critically.

Click Stimulation Rate

In normal adults and children older than approximately 18 months:

- *Rates up to **20–30 stimuli per second** have minimal effect on latency or amplitude*
- *Higher rates progressively increase latency and reduce amplitude*

Wave V is more resistant to rate effects than wave I. Increasing rate from 20 to 80 stimuli per second typically increases wave V latency by

approximately 0.4–0.6 ms, comparable to reducing stimulus intensity by 15–25 dB .

Rate Effects in Infants

Rate effects are markedly greater in neonates and young infants due to incomplete myelination and reduced synaptic efficiency.

Latency–rate slopes are:

- *Shallowest in adults*
- *Steepest in preterm infants*
- *Intermediate in term neonates*

Slower rates may be required to obtain age-appropriate ABRs, particularly in very young or premature infants.

Tone Burst Stimulation Rate

Frequency-specific ABR assessments require large numbers of waveforms. Efficient testing depends on reasonably fast rates.

Rates in the range of:

- **27–39/sec** *are effective for most tone bursts*
- *Slightly slower rates may be used for 500 and 1000 Hz stimuli*

Use of unnecessarily slow rates prolongs test time without improving response quality.

Clinical Relevance

High-rate stimulation can stress the auditory pathway and may enhance detection of neural pathology, although rate effects are not specific to retrocochlear disease and must be interpreted cautiously.

Clinical Take-Home Message

Stimulus duration, intensity, and rate are interdependent parameters that directly shape ABR quality, efficiency, and diagnostic validity. Brief onsets preserve synchrony, accurate intensity calibration underpins threshold estimation, and optimized stimulus rates reduce test time without sacrificing reliability. Mastery of these parameters is essential for evidence-based, ethical, and clinically defensible ABR practice.

Key Points

- *Intensity affects latency, amplitude, and threshold relevance.*

Common Mistakes

- *Using high intensity to infer threshold.*
- *Increasing rate to save time without adjusting interpretation.*
- *Ignoring interaction between parameters.*

Ethics

- *Transparency is a professional duty.*



CHAPTER

25

*Auditory Brainstem Response**Stimulus Parameters: Polarity*

Polarity is not a display option.

*It is a **physiological decision**.*

In ABR, polarity decides:

- *which components survive*
- *which components cancel*
- *and which pathology you are even capable of seeing*

Change polarity,

and the waveform may look cleaner—

or may lie more convincingly.

What Polarity Really Means

*Polarity describes **the direction of the initial movement of the stimulus waveform**.*

In simple terms:

- *how the speaker diaphragm moves first*
- *how the cochlear partition is stimulated*

- *how hair cells and neurons respond in time*

ABR does not respond to sound “loudness” alone.

*It responds to **timing and direction**.*

Rarefaction Polarity: Revealing the Periphery

Rarefaction causes:

- *an outward movement of the tympanic membrane*
- *earlier excitation of hair cells*
- *often slightly shorter Wave I latency*

Why Rarefaction Matters

- *Enhances cochlear microphonic visibility*
- *Improves Wave I detectability in some cases*
- *Useful in suspected ANSD*

Rarefaction listens closer to the cochlea.

That closeness comes with responsibility.

Condensation Polarity: The Other Side of the Coin

Condensation reverses the initial movement.

It often produces:

- *slightly delayed early waves*
- *different interaction with artifact*
- *complementary information*

Comparing rarefaction and condensation

*is not redundancy—it is **validation**.*

Alternating Polarity: Cleanliness with a Cost

Alternating polarity averages rarefaction and condensation.

What It Does Well

- *Reduces stimulus artifact*
- *Improves waveform appearance*
- *Simplifies interpretation*

What It Hides

- *Cancels cochlear microphonic*
- *Masks polarity-dependent information*
- *Can hide ANSD clues*

Alternating polarity makes the waveform prettier.

Not necessarily truer.

*Excellent, this is the **last technically dense pillar** in the stimulus-parameters chapter, and it is also the one that causes the **most confusion clinically**.*

*Below is a **clean, structured, clinically disciplined rewrite of the POLARITY section**, faithful to your source text in evidence, contradictions, and nuance, but transformed into **Word-ready, decision-safe content**.*

*I preserve the uncertainty where it truly exists, and I clearly separate **what is recommended** from **what is debated**, strictly based on your uploaded material .*

Stimulus Polarity in Auditory Brainstem Response Measurement Introduction

Stimulus polarity refers to the initial direction of diaphragm movement of the transducer during sound production. In auditory evoked response measurement, three categories of stimulus polarity are recognized:

- **Rarefaction polarity**, inward movement of the diaphragm producing initial negative pressure
- **Condensation polarity**, outward movement producing initial positive pressure
- **Alternating polarity**, systematic alternation between rarefaction and condensation on successive stimulus presentations

Stimulus polarity is a **clinically relevant parameter**, particularly for click-evoked ABRs, because polarity affects cochlear mechanics, neural synchrony, latency, amplitude, and artifact behavior .

Click Stimuli

Physiologic Basis

From a cochlear physiology perspective, **rarefaction polarity** is generally preferred for click-evoked ABRs. Rarefaction stimuli produce upward movement of the basilar membrane, which optimally excites inner hair cells and auditory nerve fibers. Condensation polarity produces initial downward movement and may result in relative hyperpolarization of hair cells.

As a result, rarefaction clicks typically produce:

- Slightly **shorter ABR latencies**
- Slightly **larger response amplitudes**
- More robust wave I detection

These effects are small but consistent on a population level .

Polarity Effects in Normal Adult Subjects

Early ABR studies reported:

- Shorter wave V latency for rarefaction versus condensation clicks
- Average latency differences of approximately **0.2 ms**
- Considerable inter-subject variability

Importantly:

- **15 to 30 percent** of normal adults show the opposite pattern, that is, shorter latency for condensation clicks
- Other studies show **no consistent polarity effect** on latency or amplitude

Thus, polarity effects are **statistical trends**, not absolute rules, and cannot be relied upon for individual diagnosis .

Earphone-Related Polarity Confounds

Some inconsistencies in the literature are explained by **hardware factors**, particularly in early ABR systems:

- Reversal of earphone cable polarity could inadvertently reverse stimulus polarity
- Supra-aural earphones were especially prone to this problem
- Modern insert and supra-aural earphones use keyed connectors, minimizing this risk

These findings emphasize that **nominal polarity selected on the system may not always equal delivered polarity**, especially in older systems.

Wave-Specific Effects

Polarity effects are **not uniform across ABR waves**:

- *Wave I often shows the largest and most consistent polarity effect*
- *Later waves show smaller or inconsistent effects*
- *Inter-wave latency intervals may change with polarity, confirming that the I–V interval is not a pure measure of brainstem conduction time*

Amplitude effects mirror latency effects but are more variable and more sensitive to noise and subject factors .

Polarity Effects in Infants

In neonates and young infants:

- *Polarity effects on wave I latency are **larger** than in adults*
- *Differences up to **0.13 ms** have been reported*
- *At high stimulation rates, polarity effects may be exaggerated*

*In some infants, wave I responses for rarefaction and condensation stimuli are **180 degrees out of phase**. When such responses are averaged using alternating polarity, wave I may be effectively cancelled.*

This phenomenon highlights a critical point:

Alternating polarity can obscure true neural responses in infants,
particularly wave I, and may complicate differentiation between cochlear microphonic activity and neural responses .

Tone Burst Stimuli

Lack of Consensus

*There is **no clear consensus** regarding optimal polarity for tone burst stimuli. Most investigators recommend:*

- Rarefaction polarity for higher-frequency tone bursts
- Either rarefaction or alternating polarity for lower-frequency tone bursts

The 500 Hz “Ring” Phenomenon

With single-polarity 500 Hz tone burst stimulation, a **highly periodic waveform** may occasionally appear:

- Peaks occur at twice the stimulus frequency
- The waveform persists well beyond stimulus offset
- The response resembles a frequency-following response (FFR) rather than an ABR

This phenomenon, sometimes called **ringing**, is eliminated by using **alternating polarity**, revealing a typical wave V response.

Thus, for low-frequency tone bursts, alternating polarity may be **clinically useful** when periodic waveforms obscure ABR identification.

Polarity and Auditory Pathology

Studies examining stimulus polarity in ears with auditory pathology show:

- Comparable polarity effects in normal ears and conductive hearing loss
- Altered polarity effects in steeply sloping high-frequency sensorineural loss
- No consistent polarity pattern in retrocochlear pathology

One proposed explanation is that high-frequency hearing loss reduces basal cochlear dominance, revealing phase-dependent low-frequency contributions that are normally masked in normal hearing ears .

Clinical Recommendations

Despite variability and conflicting findings, several conclusions are well supported:

- 1. **Rarefaction polarity** is the preferred default for air-conduction click-evoked ABRs*
- 2. Rarefaction clicks generally produce:*
 - Shorter latencies*
 - Larger amplitudes*
 - Higher diagnostic sensitivity*
- 3. **Alternating polarity** should not be used routinely for air-conduction click ABRs*
- 4. Alternating polarity may:*
 - Reduce stimulus artifact*
 - Obscure wave I*
 - Mask findings suggestive of auditory neuropathy spectrum disorder (ANSO)*
- 5. Alternating polarity is appropriate for:*
 - Bone-conduction ABR*
 - Low-frequency tone burst testing when ringing occurs*

Polarity and ANSD Considerations

*One of the most important clinical roles of polarity manipulation is in **identification of ANSD**:*

- True neural ABRs remain similar across polarities
- Cochlear microphonic activity reverses with polarity

Therefore, recording and comparing **separate rarefaction and condensation waveforms**, particularly at high intensities, is a powerful diagnostic strategy. A waveform that remains unchanged across polarities represents a true ABR, not CM activity .

Practical Clinical Strategy

Two clinically sound approaches exist:

- Sequential recording of rarefaction and condensation ABRs
- Simultaneous acquisition with polarity-specific waveform separation, when supported by the system

The latter approach ensures equivalent test conditions and allows later summation if alternating polarity is desired.

Clinical Take-Home Message

Stimulus polarity is not a trivial technical detail. Rarefaction polarity should be the default choice for air-conduction click ABR.

Alternating polarity has specific, limited indications and should not be used indiscriminately.

Conscious, evidence-based polarity selection enhances diagnostic sensitivity, improves waveform clarity, and reduces the risk of misinterpretation, particularly in infants and in suspected ANSD.

Polarity and Cochlear Microphonic (CM)

CM reverses with polarity.

Neural responses do not.

This simple fact makes polarity a **diagnostic tool**.

If you never look at single polarities:

- *you may miss CM*
- *you may mislabel ANSD*
- *you may falsely conclude “no response”*

Polarity is how physiology identifies itself.

The Artifact Trap

Some deflections look neural

but behave like physics.

Polarity helps you ask:

Is this biology—or electricity pretending to be biology?

If a waveform:

- *reverses exactly with polarity*
*it is **not neural**.*

Ignoring polarity invites artifact into diagnosis.

Why Polarity Is Often Misused

Polarity is often treated as:

- *a cosmetic setting*
- *a “clean-up” tool*
- *a default option*

This is dangerous.

*Clean traces without polarity awareness
are polished uncertainty.*



CHAPTER

26

Parameters and Test Protocols

*Before waves are named,
before latencies are measured,
before reports are signed—
recording decisions have already decided the outcome.*

Test protocols are not checklists.

*They are **guardrails for truth.***

Parameters do not “improve” ABR.

*They **define what is allowed to exist** in the recording.*

This chapter builds the discipline

Core Structure of an ABR Test Protocol

A defensible ABR protocol defines:

1. Stimulus strategy

- *type*
- *intensity progression*
- *rate*
- *polarity*

2. *Acquisition rules*

- *electrode placement*
- *impedance limits*
- *filters*
- *averaging criteria*

3. *Replication requirements*

- *how many runs*
- *at which levels*
- *under what conditions*

4. *Stopping criteria*

- *confidence achieved*
- *diminishing returns*
- *patient tolerance*

5. *Documentation standards*

- *what must be recorded*
- *what must be declared as limitation*

A protocol that skips any of these is incomplete.

ABR Waveform Identification and Analysis

Accurate interpretation of the auditory brainstem response depends on correct identification and systematic analysis of waveform components. Misidentification of peaks or inconsistent analytic methods are common sources of diagnostic error. This chapter provides a structured approach to ABR waveform analysis grounded in physiologic reasoning and evidence based practice.

ABR waveforms are subtle and easily misinterpreted. This chapter helps clinicians:

- *Identify true neural components reliably*
- *Distinguish physiologic responses from noise and artifact*
- *Apply consistent analytic criteria across patients and sessions*
- *Reduce false positive and false negative interpretations*

Waveform analysis is a clinical skill that improves with structured methodology.

Principles of Waveform Identification

Replication First

Waveform identification begins with replication. A peak should only be considered physiologic if it:

- *Appears consistently across repeated recordings*
- *Maintains similar latency and morphology*
- *Remains time locked to stimulus onset*

Non replicated peaks should not be labeled or interpreted.

Morphologic Consistency

True ABR components demonstrate stable shape across replications.

While minor amplitude variation is expected, overall morphology should remain consistent.

Inconsistent morphology suggests artifact or poor signal to noise ratio.

Identification of ABR Waves

Wave I

Wave I represents synchronous activity of distal auditory nerve fibers.

It is:

- *Often small in amplitude*
- *Sensitive to stimulus and recording conditions*
- *Useful for assessing peripheral neural integrity when visible*

Absence of Wave I does not preclude valid interpretation of later waves.

Wave III

Wave III reflects activity within lower brainstem pathways. It provides insight into early brainstem transmission but may be less robust than later waves.

Wave V

Wave V is the most clinically reliable ABR component. It is:

- *Typically the largest and most stable wave*
- *Visible at lower stimulus levels*
- *Used extensively for threshold estimation and neurologic assessment*

Wave V often serves as the primary reference point for analysis.

Latency Analysis

Absolute Latency

Absolute latency refers to the time interval between stimulus onset and a specific wave peak. Absolute latencies are influenced by:

- *Stimulus intensity*
- *Stimulus type*
- *Patient age*

- *Auditory system integrity*

Interpretation requires comparison with appropriate normative data.

Interpeak Latency

Interpeak latency reflects neural conduction time between waveform components. It provides information about:

- *Brainstem transmission efficiency*
- *Neural synchrony across pathway segments*
- *Effects of neurologic pathology independent of cochlear function*

Stable interpeak intervals are characteristic of normal neural conduction.

Interaural Comparisons

Comparing latencies between ears provides an internal control.

Significant interaural differences raise concern for unilateral neural pathology.

Interaural analysis reduces reliance on absolute normative values.

Take-Home Messages

- *Accurate ABR analysis depends on systematic waveform identification*
- *Replication is mandatory before labeling peak*



CHAPTER

27

*Click-Evoked ABRs**Bone Conduction Stimulation*

Bone-conduction ABR is not air-conduction ABR without the ear canal.

What BC-Click ABR Really Tests

BC-Click ABR asks a very specific question:

Is there synchronous neural activity when the cochlea is stimulated directly through skull vibration?

It is not asking:

- *which ear responded (without masking)*
- *what the frequency-specific threshold is*
- *how well the patient hears*

*BC-Click ABR is about **pathway access**, not hearing ability.*

Why Bone Conduction Is Clinically Powerful

Used correctly, BC-Click ABR helps:

- *differentiate conductive vs sensorineural components*

- *identify the presence of a cochlear response when AC is compromised*
- *support cross-check principles in complex cases*

*It answers the type question—
not the degree question.*

Bone conduction introduces:

- *complex vibration modes*
- *bilateral cochlear stimulation*
- *frequency distortion*
- *vibrotactile responses at higher levels*

This means:

- *side specificity is lost without masking*
- *intensity does not translate cleanly to cochlear level*
- *“thresholds” become conceptual, not absolute*

*If you forget the skull,
the skull will embarrass your report.*

*There is **no such thing** as unmasked, ear-specific BC-ABR.*

*Bone conduction **always** stimulates both sides.*

Without masking:

- *you cannot assign the response to one ear*
- *unilateral conclusions are invalid*
- *conductive vs sensorineural inference collapses*

BC-Click ABR without masking

*is **documentation**, not diagnosis.*

Indication

Abnormalities in

◆ *External ear*

◆ *Middle ear*

eg. canal occlusion in newborns, infants who have cranial-facial anomalies as congenital atresia.

◆ *Provides a direct estimation of child sensorineural status
(presence/absence of a sensorineural component)*



Figure 25.1. congenital atresia.

Test Protocol

- ◆ *Air conduction ABR thresholds*
- ◆ *Bone conduction ABR thresholds*
- ◆ *Compare two thresholds*

BC ABR Recording

Transducer

- ◆ *Bone oscillator (Radioear B-71)*
- ◆ *Head phone /insert phone*

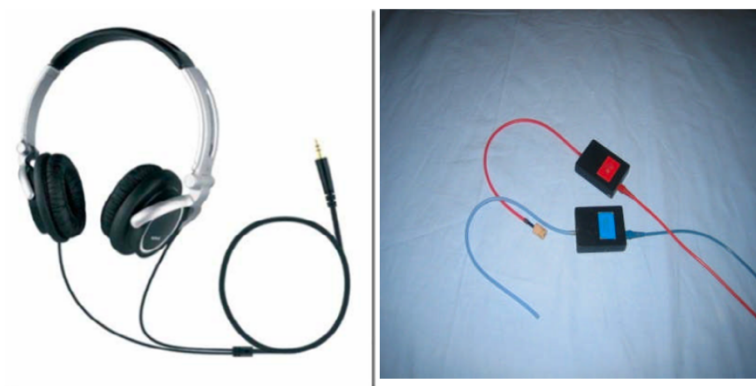


Figure 25.2. congenital atresia.

BC -ABR Recording

Transducer

- ◆ *The oscillator can be hold with*

one-finger pressed against the mastoid

◆ *Elastic headband with an adjustable Velcro closure holds the bone vibrator securely on the high mastoid*

Electrode Placement

◆ ***The Active*** electrode on the scalp at the vertex (near Cz position)

◆ ***The Reference*** electrode over ipsilateral mastoid

◆ ***The ground*** electrode over contralateral mastoid

Electrode impedances must be < 5 KOhms

Stimuli

Ipsilateral

◆ ***Clicks*** (broad band clicks)

◆ ***Tone burst*** (500Hz and 2000Hz)

Contralateral masking (by head phone or insert ear phone) specially in cases of congenital atresia

Intensity

Maximum intensity for BC is around 60 dBnHL

◆ *Clicks 60 dBnHL*

◆ *500 Hz tone burst 50dBnHL*

◆ *2000 Hz tone burst 60 dBnHL*

Repetition rate 21.1 p/sec

Filter same as AC ABR

◆ *Filter (100-3000Hz)*

◆ *Analysis Time 15-20 ms from stimulus*

◆ *No. of sweeps variable (1000-4000)*

- ◆ Two or more responses to demonstrate replicability

Response

- ◆ BC have essentially same wave morphology
- ◆ But --- latencies approximately longer 0.5 msec in adults and older children (increased travel time of the lower frequency BC stimulus)
- ◆ Less pronounced and unpredictable in younger infants and neonates (due to maturation difference)

Interpretation

Comment on :

- ◆ Waves identification and repeatability
- ◆ Waves latency
- ◆ Threshold
- ◆ **Normal response:** BC-ABR down to minimum level (40 dBnHL)
- ◆ **Absent BC-ABR** at maximum BC level indicates the presence of a significant sensorineural component.
- ◆ **Elevated BC-ABR threshold** with a present response at intensity above minimum level suggests a sensorineural component in the mild/moderate range

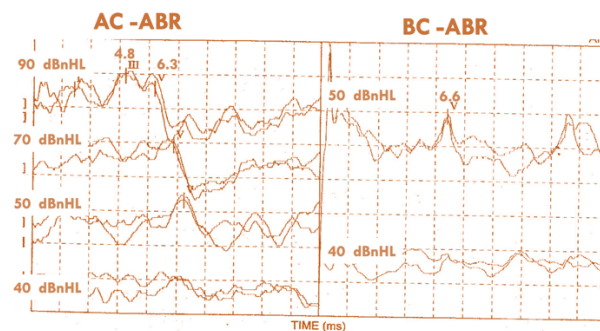


Figure 25.3. BC-ABR.

- Sufficient space should be allowed for a bone vibrator to be placed on the mastoid without interfering with the electrode or may use earlobes electrodes
- Use alternating polarity for BC to help reduce stimulus artifact that is generated by the oscillator itself.
- BC -clicks have lower dominant frequency around (1000-2000Hz) vs (2000-4000Hz) for AC clicks

Indications for Bone Conduction ABR

Bone conduction ABR is clinically indicated when one or more of the following are present:

1. History suggestive of middle ear disease
2. Abnormal otoscopic findings
3. Abnormal aural immittance results
4. Air-conduction ABR pattern consistent with conductive loss, especially
 - Abnormally delayed wave I latency at high stimulus intensity levels

Bone conduction ABR is primarily intended to:

- Differentiate **conductive versus sensorineural hearing loss**
- Confirm middle ear contribution to ABR latency abnormalities
- Support early management decisions in infants .

Stimulus Parameters for Bone Conduction ABR

Transducer

- **B71 or B81 bone vibrator**

- *The bone vibrator supplied by the ABR system manufacturer should be used*
- *Insert earphones **must remain in place** during bone conduction ABR to allow masking if needed*

Stimulus Type

- **Click** or **chirp click**
- *Click stimuli are preferred because the goal is **type of hearing loss**, not frequency-specific threshold estimation*
- *Chirp clicks may be used to enhance wave V amplitude*

Placement Site

- **Mastoid bone** is the customary placement site
- *In infants, placement anywhere on the temporal bone is generally adequate*
- *Secure coupling is essential for consistent stimulation*

Duration

- **0.1 ms (100 microseconds)**
- *Same nominal duration as air-conduction clicks*
- *Note that frequency response differs due to bone vibrator characteristics*

Polarity

- **Alternating polarity**
- *Required to reduce unavoidable stimulus artifact associated with bone conduction stimulation*
- *Single polarity stimulation is not recommended for bone conduction ABR*

Stimulus Rate

- ***21.1/sec or 11.1/sec***
- *Slower rates may improve wave I amplitude and overall waveform clarity*
- *Rate selection should balance response quality and test duration*

Intensity

- ***Variable***, with a maximum output of approximately ***50–55 dB nHL***
- *Bone conduction stimulus levels must be **biologically verified***
- *Do not assume equivalence with air-conduction dB nHL values*

Number of Repetitions (Sweeps)

- ***Variable***, based on signal-to-noise ratio (SNR)
- *Clinical target is an **ABR-to-noise ratio of at least 3:1***
- *Typical range:*
 - *500 to 2000 sweeps at moderate levels*
 - *More sweeps required near threshold or in noisy environments*

Masking

- ***Variable***, applied to the non-test ear when indicated
- *Clear identification of **wave I** confirms test-ear specificity and eliminates the need for masking*
- *If wave I is absent or ambiguous:*
 - *Apply masking noise of approximately **50 dB** via insert earphones*

Special considerations:

- Masking is generally **not required in infants under 6 months**
- High interaural attenuation exists due to incomplete cranial bone fusion in young infants .

Acquisition Parameters for Bone Conduction ABR

Electrode Configuration

- **Non-inverting electrode:** Fz (high forehead), preferred in infants
- **Inverting electrode:** Ipsilateral earlobe (Ai)
 - Earlobe placement reduces stimulus artifact compared with mastoid placement
- **Ground electrode:** Fpz or any electrically neutral body site

An alternative **Ac–Ai horizontal array** may be useful when excessive electrical artifact is present.

Filter Settings

- **High-pass filter:** 30 Hz (75 Hz acceptable in selected cases)
 - High-pass filters ≥ 100 Hz should be avoided
- **Low-pass filter:** 3000 Hz
 - May be reduced to 2000 or 1500 Hz if high-frequency artifact is problematic
- **Notch filter:** OFF
 - Notch filtering reduces low-frequency energy critical for infant ABRs and should not be used

Amplification

- **$\times 100,000$**
- Equivalent to a sensitivity of approximately $\pm 25 \mu V$

- *Adequate for infant ABR screening and diagnostic testing*

Analysis Time

- **15 ms**
- *Encompasses the entire bone conduction ABR waveform, including wave V and subsequent troughs*
- *Adequate even at low stimulus levels and in premature infants*

Pre-Stimulus Baseline

- **1 ms**
- *Provides real-time assessment of background noise and recording stability*

Display Gain

- **0.25 to 0.30 μV**
- *Optimizes visualization of wave V, typically around 0.5 μV*
- *Excessively high display gain (e.g., 0.80 μV) flattens waveforms and obscures low-level responses*

Number of Runs

- **At least two replications**
- *A response must be reproducible in latency and morphology*
- *Fundamental rule applies:*

If the waveform does not replicate, the response must be questioned

Clinical Take-Home Message

Bone conduction click-evoked ABR is an essential component of pediatric diagnostic assessment whenever conductive hearing loss is possible. Proper stimulus selection, artifact control, and acquisition parameter optimization are critical for reliable interpretation. When

performed correctly, bone conduction ABR allows confident differentiation of conductive and sensorineural hearing loss and prevents misdiagnosis that can delay appropriate intervention.

Key Points

- *BC-Click ABR is a different physiological experiment from AC-ABR.*
- *It stimulates both cochleae via skull vibration.*
- *Masking is mandatory for ear-specific conclusions.*
- *Threshold and frequency specificity are limited.*

Documentation

- *State BC transducer type and placement.*
- *Document masking noise and level.*
- *Describe limitations clearly.*

Report Writing

- *Avoid ear-specific language without masking.*



CHAPTER

28

Frequency-Specific ABRs
Tone-Burst Stimulation

If the click asks,

“Can the system fire together?”

The tone burst asks the harder question:

“Where—and how—does it fail?”

Tone-burst ABR is not weak.

*It is **honest**.*

It sacrifices beauty

to gain relevance.

And relevance is what decisions need.

Why Frequency-Specific ABR Exists

No patient hears in clicks.

No hearing aid is fitted to synchrony.

No cochlear implant candidacy is decided by morphology alone.

Clinical decisions require:

- *frequency information*

- *threshold estimation*
- *configuration awareness*

*Tone-burst ABR exists because **life happens by frequency.***

What a Tone Burst Really Is

A tone burst is:

- *frequency-limited*
- *temporally shaped*
- *physiologically negotiated*

Its rise, plateau, and fall times decide:

- *synchrony*
- *spectral splatter*
- *latency behavior*

*A tone burst is a **compromise by design:***

less synchrony for more specificity.

The Cost of Specificity

Compared to click ABR, tone-burst ABR produces:

- *smaller amplitudes*
- *longer latencies*
- *less dramatic waveforms*

This is not failure.

*This is **truth without exaggeration.***

If tone-burst ABR looks “weak,”

it is usually because it is asking a harder question.

Frequency Matters—But So Does How You Ask

Frequency-specific ABR accuracy depends on:

- *stimulus duration*
- *rise/fall times*
- *intensity stepping*
- *rate*
- *transducer choice*

Poorly designed tone bursts create:

- *false thresholds*
- *misleading configurations*
- *confident errors*

Frequency specificity is not automatic.

*It is **engineered**.*

Latency in Tone-Burst ABR: Different Rules Apply

Tone-burst latencies:

- *are longer than click latencies*
- *vary by frequency*
- *shift with stimulus envelope*

*Comparing tone-burst latency to click norms
is a category error.*

*Latency here is **contextual**, not absolute.*

Threshold Estimation: Where Tone-Burst ABR Shines

Tone-burst ABR is the foundation of:

- *pediatric threshold estimation*
- *hearing-aid candidacy*
- *early intervention planning*

But:

- *thresholds are estimates*
- *correction factors are required*
- *confirmation is essential*

*Tone-burst ABR guides decisions—
it does not replace behavioral truth.*

Low Frequencies: The Hardest Truth

Low-frequency tone-burst ABR is:

- *slower*
- *noisier*
- *less forgiving*

Which is exactly why it matters.

*Most false reassurance in pediatrics
comes from **ignoring low frequencies**.*

*If you skip them,
your audiogram lies politely.*

Air vs Bone in Tone-Burst ABR

Tone-burst ABR can be applied via:

- *air conduction*
- *bone conduction*

But bone-conduction tone-burst ABR:

- *demands masking*
- *suffers from limited output*
- *requires extreme interpretive restraint*

*Use it to clarify **type**,
not to pretend precision.*

Why Tone-Burst ABR Is Often Avoided

Because it:

- *takes time*
- *demands patience*
- *exposes uncertainty*

Click-ABR feels confident.

Tone-burst ABR feels responsible.

*Clinicians who value speed over accuracy
avoid tone-burst ABR.*

*Clinicians who value outcomes
embrace it.*



CHAPTER

29

Enhancing ABRs and Minimizing Noise

Noise is not the enemy.

Ignorance of noise is.

Every ABR recording is a negotiation:

- *between physiology and physics*
- *between patience and pressure*
- *between enhancement and distortion*

Enhancing ABR does not mean making it louder, cleaner, or prettier.

*It means **making the neural truth accessible—without rewriting it.***

First Principle: You Don't Eliminate Noise—You Manage It

Noise comes from:

- *muscle activity*
- *movement*
- *electrical interference*
- *electrode instability*
- *environmental chaos*

*Trying to “erase” noise aggressively
often erases physiology with it.*

The goal is not silence.

*The goal is **signal dominance**.*

Patient State: The Strongest Noise Filter

The most powerful noise-reduction tool is not software.

*It is **patient state**.*

- *Sleep > sedation > restraint*
- *Calm > force*
- *Preparation > correction*

A relaxed patient improves:

- *baseline stability*
- *averaging efficiency*
- *waveform reliability*

No filter can compensate for tension.

Electrode Integrity: Noise Starts at the Skin

Good electrode prep:

- *lowers impedance*
- *stabilizes baselines*
- *prevents drift*

Balanced impedance matters more than low impedance.

A single unstable electrode can:

- *mimic pathology*
- *destroy replication*
- *waste hours*

Noise management begins *before the first click*.

Averaging: Let Math Work—Not Desperation

*Averaging improves signal-to-noise ratio
by reinforcing time-locked neural activity.*

But:

- *averaging noise longer does not make it signal*
- *excessive averaging wastes time*
- *insufficient averaging invites coincidence*

Stop averaging when:

- *replication confirms stability*
- *additional runs add nothing*

Averaging is patience with boundaries.

Filtering: The Most Enhancement Tool

Filters are seductive because they work fast.

They can:

- *sharpen peaks*
- *reduce baseline clutter*
- *improve visual clarity*

They can also:

- *distort waveform morphology*
- *shift apparent latency*
- *erase clinically relevant components*

*Filters should **reveal**—not redesign.*

*If filtering changes the story,
the story was not stable to begin with.*

Artifact Rejection: Friend, Not Tyrant

*Artifact rejection protects integrity—
until it becomes aggressive.*

Over-rejection:

- *rejects physiology*
- *prolongs testing*
- *increases frustration*

Under-rejection:

- *accepts garbage politely*

Artifact rejection should:

- *target obvious non-neural events*
- *remain transparent*
- *never replace clinical judgment*

Stimulus Strategy: Enhancement Without Cheating

*Sometimes the best noise reduction is **better stimulus design**:*

- *appropriate rate*
- *correct intensity*
- *thoughtful polarity*
- *transducer choice*

*If enhancement requires extreme settings,
the protocol—not the patient—is wrong.*

Environment: The Forgotten Variable

Noise lives in:

- *power lines*
- *mobile devices*

- *nearby equipment*
- *poor grounding*

*A noisy room creates noisy data—
no matter how good the clinician is.*

Environmental discipline is clinical discipline.

When “Enhancement” Becomes Data Corruption

Red flags that enhancement crossed the line:

- *waveforms appear only after heavy filtering*
- *latency shifts dramatically with minor setting changes*
- *replication fails despite “clean” traces*

*If enhancement is required to believe the ABR,
the ABR is not ready to be believed.*

Many ABR errors are born here:

- *good intentions*
- *time pressure*
- *desire for clarity*

*This chapter exists to protect clinicians
from accidentally enhancing **confidence instead of truth.***

Key Points

- *Noise cannot be eliminated—only managed.*
- *Patient state is the strongest noise filter.*



CHAPTER

30

Guidelines for ABR Analysis

ABR analysis is not a talent.

*It is **a discipline**.*

Guidelines exist because:

- *intuition drifts*
- *pressure distorts judgment*
- *confidence grows faster than certainty*

ABR does not need smarter eyes.

*It needs **stricter rules**.*

Principle Zero: Analysis Begins Before Interpretation

Before naming a wave, confirm:

- *stimulus appropriateness*
- *acquisition integrity*
- *replication*
- *noise control*

If these are weak,

analysis is postponed—not performed.

*Interpretation without prerequisites
is storytelling.*

Guideline 1: Replication Is the Gatekeeper

No response is valid until it replicates.

- *One run = hypothesis*
- *Two consistent runs = evidence*

Replication must be:

- *at the same level*
- *under the same parameters*
- *temporally stable*

*If replication fails,
analysis stops.*

Guideline 2: Identify Waves by Behavior, Not Shape

A true ABR wave:

- *appears within expected latency range*
- *grows systematically with intensity*
- *shifts predictably with rate*
- *persists across runs*

Shape alone is insufficient.

*A beautiful peak that behaves badly
is not a wave.*

Guideline 3: Latency Means Nothing Without Context

Latency interpretation requires:

- *stimulus type and rate*
- *transducer delay correction*

- *patient age and maturation*
- *analysis window appropriateness*

Numbers without context

are decimals pretending to be diagnosis.

Guideline 4: Amplitude Is Supportive—Never Decisive

Amplitude:

- *is highly variable*
- *is noise-sensitive*
- *depends on geometry*

Use amplitude to:

- *support wave identification*
- *assess robustness*

*Never use amplitude alone
to diagnose pathology.*

Guideline 5: Symmetry Is Informative—Not Absolute

Interaural comparison is valid only if:

- *acquisition conditions are identical*
- *impedance is balanced*
- *stimulus levels are equivalent*

Asymmetry created by setup

is still asymmetry—but not disease.

Guideline 6: Parameter Changes Redefine Interpretation

Any change in:

- *stimulus*
- *rate*

- *polarity*
- *filtering*

resets interpretation rules.

*Never compare responses across runs
without accounting for parameter changes.*

Guideline 7: Artifact Must Be Actively Challenged

Suspect artifact when:

- *polarity reverses the waveform exactly*
- *latency remains fixed across intensities*
- *minor setup changes abolish the response*

*If artifact is possible,
prove physiology—or withdraw the claim.*

Guideline 8: “No Response” Is a Diagnosis of Exclusion

Before concluding “no response,” confirm:

- *adequate intensity*
- *correct analysis window*
- *polarity exploration*
- *acceptable noise levels*

*“No response” without exclusion
is an unfinished sentence.*

Guideline 9: Match Analysis to Clinical Purpose

Analysis differs for:

- *screening*
- *threshold estimation*
- *neurodiagnostic evaluation*

*Applying the wrong analytic lens
creates false conclusions.*

Purpose controls priority.

Guideline 10: State Limitations Explicitly

Every ABR has limits:

- *patient state*
- *noise*
- *incomplete frequencies*
- *time constraints*

Unstated limitations

become misinterpretations later.

Transparency is part of analysis.

Why These Guidelines Matter

Most ABR errors survive because:

- *they sound confident*
- *they look clean*
- *no one challenged the process*

*Guidelines slow analysis down—
just enough to make it safe.*

Tone Burst Stimulation

*Frequency-specific estimation of auditory thresholds using tone burst ABR is now **standard of care** for hearing assessment in infants and young children. Contemporary clinical guidelines recommend routine ABR testing with tone burst stimuli across the frequency range **500 to***

4000 Hz to accurately define the **degree and configuration of hearing loss**.

Accurate frequency-specific threshold estimation is essential for:

- *Early hearing aid fitting*
- *Cochlear implant candidacy decisions*
- *Prognosis for speech and language development*
- *Monitoring auditory development in at-risk infants*

*Tone burst ABR protocols described here reflect **extensive clinical research** and represent evidence-based best practice for pediatric assessment .*

Stimulus Parameters for Tone Burst ABR

Transducer

- ***Insert earphones***
- *Insert earphones are strongly preferred due to:*
 - *Superior interaural attenuation*
 - *Reduced stimulus artifact*
 - *Improved patient comfort*
 - *Reduced risk of ear canal collapse*
 - *Better infection control*

Stimulus Type

- ***Conventional tone bursts or chirp tone bursts***
- *Chirp stimuli:*
 - *Produce larger ABR amplitudes*
 - *Improve wave V detectability*
 - *Reduce test time*

- *Use of chirps is encouraged when available and validated*

Polarity

- **Rarefaction** or **alternating polarity**
- Alternating polarity is useful at **500 Hz** to minimize frequency-following type responses
- Rarefaction polarity is generally effective for higher frequencies

Stimulus Rate

- **Approximately 37.7 stimuli per second**
- Moderately fast rates:
 - Improve efficiency
 - Maintain wave V clarity in infants
- Rates up to 49.1/sec may be used
- Odd-numbered rates reduce interaction with 60 Hz electrical noise

Envelope and Ramping

- **Blackman windowing**
- Blackman ramping:
 - Reduces spectral splatter
 - Improves frequency specificity
 - Preserves acceptable neural synchrony

Duration

- **Variable**, frequency dependent
- Standard configuration:
 - 2 cycles rise
 - 0 cycles plateau

- 2 cycles fall
- Duration in milliseconds increases as stimulus frequency decreases

Intensity

- **Variable**, displayed in dB nHL
- Screen intensity values must be **biologically verified**
- Behavioral thresholds for tone bursts should be established in the same test environment when possible
- Correction factors may be required across clinics and rooms

Acquisition Parameters

Electrode Configuration

- **Non-inverting electrode**: Fz (high forehead)
- **Inverting electrode**: Ipsilateral earlobe (Ai)
 - Lower impedance
 - Larger wave I amplitude
 - Less stimulus artifact than mastoid placement
- **Ground electrode**: Fpz or contralateral earlobe

Filter Settings

- **High-pass filter**: 30 Hz
 - May increase to 75 or 100 Hz if necessary
- **Low-pass filter**: 3000 Hz
- **Notch filter**: OFF
 - Notch filtering removes low-frequency energy critical to infant ABRs

Analysis Time

- **15 ms**
 - Adequate for clicks and higher-frequency tone bursts
- **20 ms**
 - Recommended for 1000 Hz and 500 Hz tone bursts
 - Necessary in infants and in hearing loss with delayed wave V

Display Gain

- **0.25 to 0.30 μV**
- Optimizes visualization of wave V, typically around 0.5 μV
- Excessively large display scales flatten waveforms and obscure responses

Signal Averaging (Sweeps)

- **Variable**, based on signal-to-noise ratio
- General guidance:
 - Minimum of ~500 sweeps for consistency
 - Increase sweeps near threshold or in noisy conditions
- Averaging should be **terminated early** once a clear and replicable response is observed

Creating and Using Test Protocols

Clinicians are strongly encouraged to create **dedicated ABR protocols** within their evoked response system.

At minimum, protocols should include:

1. Air-conduction click ABR
2. Bone-conduction click ABR
3. Tone burst ABR protocols for:

- 500 Hz
- 1000 Hz
- 2000 Hz
- 4000 Hz

Each protocol should be:

- *Clearly labeled*
- *Clinic-specific*
- *Easily retrievable during testing*

*Protocols serve as **starting points**, not rigid rules. Experienced clinicians adjust parameters dynamically to optimize waveform quality during testing .*

Saving Test Time Without Sacrificing Quality

Efficient ABR testing is a learned clinical skill. The following strategies are strongly recommended:

- *Continuously monitor waveforms during averaging*
- *Begin testing with **high-intensity click stimuli** (≥ 80 dB nHL)*
- *Use click ABRs to rapidly assess neural integrity and guide tone burst strategy*
- *Stop averaging immediately once a clear response is detected*
- *Always replicate responses for confirmation*
- *Decrease intensity in large steps (up to 40 dB) when high-level responses are clearly normal*
- *Plan each subsequent step before finishing the current run*

Efficient testing maximizes diagnostic yield while minimizing sedation time, patient stress, and clinic burden .

Concluding Comments

*This chapter complements the preceding review of stimulus parameters in ABR measurement. Together, these chapters form the scientific and clinical foundation for **evidence-based ABR protocols**.*

High-quality ABR recordings depend on:

- *Thoughtful stimulus selection*
- *Appropriate acquisition parameters*
- *Well-designed test protocols*
- *Quiet, stable patients*
- *Low-noise test environments*

*Tester experience and judgment matter, but even expert clinicians cannot consistently obtain reliable ABRs using poorly designed protocols. **Protocol quality is a primary determinant of ABR success***

*Analysis of the Auditory Brainstem Response requires a disciplined understanding of **how ABR waveforms are generated, displayed, and interpreted**, and equally important, **how they can mislead**. While fundamental principles of evoked response measurement apply broadly, ABR analysis presents unique challenges due to:*

- *extremely small response amplitudes*
- *dependence on neural synchrony*
- *vulnerability to noise and artifact*
- *normal inter- and intra-subject variability*

*ABRs are conventionally analyzed in the **time domain**, with waveform amplitude displayed in microvolts as a function of time in milliseconds. Although frequency-domain representations can reveal*

spectral characteristics of the response, routine clinical interpretation of ABR depends primarily on **latency and amplitude analysis in the time domain**.

Fundamental Concepts in ABR Waveform Analysis

Morphology

ABR morphology refers to the overall **shape and pattern** of the waveform. Morphology is often judged relative to an expected “normal” appearance, but this judgment is inherently **subjective**.

A waveform may appear morphologically poor even when:

- latency values are normal
- amplitude values are within expected limits
- the response is reproducible

Conversely, visually appealing waveforms may still represent abnormal physiology. Morphology alone is **never sufficient** for clinical interpretation and must be considered alongside latency, amplitude, and repeatability.

Latency Analysis

Definition

Latency is the time interval between stimulus onset and a defined point on an ABR wave, usually a positive peak or shoulder. Latency is always expressed in milliseconds.

Two types of latency are used:

- **Absolute latency**, measured from stimulus onset to a wave
- **Inter-wave latency**, measured between two waves, most commonly:

- I–III
- III–V
- I–V

Inter-wave latencies are often interpreted as indices of neural transmission time through the auditory brainstem, reflecting both axonal conduction and synaptic delay .

Marking ABR Peaks

*Latency values depend entirely on **how the peak is defined**.*

Common approaches include:

- *marking the point of maximum amplitude*
- *marking the shoulder preceding the steep negative slope, especially for wave V*

*Wave V frequently appears as part of a **IV–V complex** without a discrete peak. In such cases, marking latency from the shoulder rather than the maximum amplitude is clinically justified and often preferred.*

Inconsistent peak marking leads directly to:

- *incorrect latency values*
- *false interaural asymmetries*
- *erroneous diagnoses*

Latency–Intensity Relationship

ABR latencies increase systematically as stimulus intensity decreases.

For click-evoked ABRs:

- *decreasing intensity from about 80 dB nHL to near threshold increases wave V latency by approximately **3.5 ms***

- *this relationship forms the basis of the **latency–intensity function***

Latency–intensity functions remain a cornerstone of ABR interpretation in both pediatric and neurodiagnostic applications .

Amplitude Analysis

Amplitude is the second major ABR parameter and is always expressed in microvolts.

Methods of Amplitude Measurement

Common methods include:

- *peak-to-preceding trough, often used for waves I and III*
- *peak-to-following trough, commonly used for wave V*

Absolute amplitude is highly variable and sensitive to:

- *EEG noise*
- *muscle artifact*
- *electrode placement*
- *filter settings*
- *subject state*

*For this reason, **relative amplitude measures** are often preferred.*

Wave V to Wave I Amplitude Ratio

*The **wave V/I amplitude ratio** is the most widely used relative amplitude measure.*

- *A ratio of **1.0 or greater** is typical*
- *Ratios below **0.5** are conservatively considered abnormal*
- *Ratios between 0.5 and 1.0 occur in a minority of normal subjects and are not diagnostic in isolation*

*In infants and young children, a smaller V/I ratio may reflect **neural immaturity**, not pathology .*

Polarity and Wave Direction

ABR polarity depends on:

- *electrode placement*
- *assignment of electrodes to non-inverting and inverting amplifier inputs*

By convention:

- *positive voltage is plotted upward*
- *waves I, III, and V appear as upward deflections*

This convention is not universal, and some investigators plot waveforms inverted. Clinicians must always confirm waveform orientation before analysis.

*ABR waves represent **far-field potentials** generated by multiple overlapping neural sources. A single ABR wave does not correspond to a single anatomic generator, and the relationship between waveform peaks and auditory nuclei is complex and not fully understood .*

Normal Variations in ABR Waveforms

ABR waveforms show substantial normal variability:

- *between individuals*
- *between ears*
- *across test sessions*
- *even between repeated runs*

Waveforms can be as distinctive as fingerprints. Subtle differences are clinically irrelevant as long as criteria for normality and abnormality are applied consistently.

Latency-based analysis remains the most reliable approach because latency values are far more stable than amplitude or morphology .

The Art of Peak Picking

Accurate peak identification is a learned clinical skill.

Two fundamental strategies exist:

- 1. Maximum amplitude selection*
- 2. Shoulder selection before the steep negative slope*

Neither approach is universally correct. In practice:

- maximum amplitude works well for waves I and III*
- shoulder selection is often superior for wave V*

*The key principle is **internal consistency**. A laboratory must adopt and consistently apply the same criteria for peak selection to avoid systematic error.*

Repeatability and Reliability

*An ABR is not considered valid unless it is **repeatable**.*

Minimum requirement:

- at least two waveforms recorded under identical conditions*
- waveforms must be similar in latency and morphology*

A commonly used reliability criterion:

- wave V latency difference between runs $\leq$ **0.2 ms***

If a waveform does not replicate, the clinician must modify test conditions and investigate the cause. No single factor contributes more to diagnostic confidence than repeatability .

Variability Versus Measurement Error

Two sources of uncertainty exist:

1. ***Biological variability***, including neural synchrony and subject state
2. ***Measurement variability***, including operator decisions and analysis criteria

Amplitude is particularly vulnerable to both forms of variability.

Latency is more robust and therefore more reliable clinically.

Enhancing ABRs and Reducing Noise

The guiding clinical principle is simple:

Whatever works to enhance the response and reduce noise, do it.

Strategies to Increase ABR Amplitude

- *Increase stimulus intensity*
- *Use chirp stimuli*
- *Slow stimulus rate*
- *Optimize electrode placement*
- *Adjust polarity*

Strategies to Reduce Noise

- *Increase number of sweeps*
- *Use weighted or summed averaging*
- *Optimize filter settings*
- *Minimize patient movement*

- *Improve test environment*

Role of Chirp Stimuli

Chirp stimuli compensate for cochlear traveling wave delay and produce:

- *larger wave V amplitudes*
- *improved signal-to-noise ratio*
- *better detectability near threshold*
- *reduced test time*

Level-specific chirps extend these advantages across a wide range of stimulus intensities and are now well validated in infants and adults .

Guidelines for ABR Analysis

*Formal guidelines, such as those from the **UK Newborn Hearing Screening Programme**, provide structured criteria for:*

- *defining presence or absence of a response*
- *resolving inconclusive results*
- *defining ABR threshold*

Key criterion:

- *wave V amplitude must be at least **three times the background noise***

Three outcome categories are defined:

- ***Clear Response (CR)***
- ***Response Absent (RA)***
- ***Inconclusive (Inc)***

*ABR threshold is defined as the **lowest intensity producing a clear response**, with absence of response at a lower level under equivalent recording conditions .*

Clinical Take-Home Message

ABR analysis is both a science and a disciplined clinical skill.

Reliable interpretation depends on:

- *repeatable waveforms*
- *consistent analysis criteria*
- *thoughtful use of latency and amplitude measures*
- *aggressive noise control*
- *evidence-based protocols*

*When uncertainty exists, the solution is almost never more interpretation, but **better recording**.*

Key Points

- *Replication is mandatory.*



CHAPTER

31

Abnormal ABR Patterns

Abnormal ABR patterns are not surprises.

*They are **messages**.*

Messages written in timing, symmetry, growth, and failure to replicate.

*They do not scream pathology—
they **whisper logic**.*

The danger is not abnormality.

*The danger is **misclassification**.*

First Principle: Abnormal Does Not Mean Pathological

An ABR can be abnormal because:

- *physiology is different*
- *maturation is incomplete*
- *parameters are aggressive*
- *acquisition is biased*

*Pathology is **one** explanation—not the default.*

Abnormality demands analysis.

Pathology demands exclusion.

Pattern-Based Thinking: Stop Chasing Single Waves

*ABR abnormalities must be recognized as **patterns**, not peaks.*

Patterns include:

- *latency behavior across intensity*
- *interaural relationships*
- *rate effects*
- *replication stability*

Single-wave obsession creates single-minded errors.

Pattern 1: Prolonged Absolute Latencies

What It Looks Like

- *Waves present*
- *All major peaks shifted right*
- *Interpeak intervals may be normal*

What It Might Mean

- *delayed neural conduction*
- *immature auditory system*
- *high stimulation rate*
- *uncorrected transducer delay*

What It Does NOT Automatically Mean

- *brainstem lesion*

Context decides truth.

Pattern 2: Prolonged Interpeak Intervals

What It Looks Like

- *I–III, III–V, or I–V prolonged*
- *Absolute latencies may appear acceptable*

What It Suggests

- *conduction delay between neural generators*
- *demyelination or compression (after exclusion)*

Red Flag

- *asymmetry between ears under identical conditions*

Interpeaks speak when absolute latencies are quiet.

Pattern 3: Absent or Poorly Defined Wave I

What It Looks Like

- *Later waves present*
- *Wave I absent or inconsistent*

Possible Explanations

- *cochlear synaptopathy*
- *poor electrode placement*
- *stimulus polarity effects*
- *transducer issues*

*Absent Wave I is a **question**, not a verdict.*

Pattern 4: Asymmetric Responses

What It Looks Like

- *clear interaural differences*
- *delayed or absent waves on one side*

Before You Diagnose

Confirm:

- *equal stimulus levels*

- *balanced impedance*
- *masking adequacy*
- *identical parameters*

True asymmetry survives correction.

Pattern 5: Rate-Sensitive Abnormalities

What It Looks Like

- *normal morphology at slow rates*
- *latency prolongation or waveform degradation at fast rates*

What It Suggests

- *reduced neural reserve*
- *vulnerability to stress*

*Rate is a **physiological stress test**—
not a speed trick.*

Pattern 6: Absent ABR with Preserved CM

What It Looks Like

- *no replicable neural waves*
- *polarity-reversing cochlear microphonic present*

What It Indicates

- *auditory neuropathy spectrum disorder (ANSO)
(after exclusion of artifact)*

*This pattern is diagnostic **only** if polarity logic is respected.*

Pattern 7: Poor Replication Despite “Clean” Traces

What It Looks Like

- *nice-looking waves*
- *inconsistent across runs*

What It Usually Means

- *noise alignment*
- *overfiltering*

*If it does not replicate,
it does not exist clinically.*

Pattern 8: Threshold-Inconsistent Behavior

What It Looks Like

- *responses disappear unpredictably*
- *thresholds jump between runs*

Possible Causes

- *patient state changes*
- *masking errors*

*Threshold chaos is often **protocol chaos**.*

Why Pattern Recognition Matters

Pathology rarely announces itself clearly.

*It **emerges** from consistency across conditions.*

*Clinicians who chase single abnormalities
miss the story written across runs.*

Key Points

- *Replication and parameter review are essential.*
- *Many abnormalities are non-pathological.*

Common Mistakes

- *ANSD diagnosis without polarity logic.*



CHAPTER

32

Non-Pathologic Subject Factors

Not every abnormal ABR belongs to disease.

*Some belong to **biology behaving normally under unusual conditions.***

The most ABR mistake is not missing pathology.

*It is **creating pathology where none exists.***

*This chapter exists to protect patients
from diagnoses that come from forgetting
that the subject is **human.***

Non-Pathologic Subject Factors: When the Brainstem Is Innocent

ABR is exquisitely sensitive.

That sensitivity cuts both ways.

*Many factors alter ABR **without pathology:***

- *age*
- *state of arousal*
- *temperature*
- *fatigue*

- *muscle tone*
- *cooperation*

*If you ignore these,
you will diagnose physiology as disease.*

Age and Maturation: Delay Is Not Damage

In neonates and infants:

- *myelination is incomplete*
- *synaptic timing is immature*
- *latencies are naturally prolonged*

*Delayed waves in early life
often mean **development**, not dysfunction.*

*Comparing infant ABRs to adult norms
is analytical malpractice.*

State of Arousal: Sleep, Sedation, and Stress

ABR is robust—but not invincible.

- *Natural sleep improves SNR*
- *Agitation increases noise*
- *Muscle tension creates artifact*

*Stress does not create pathology—
but it can **hide physiology**.*

*A calm patient often “recovers” from disease
that never existed.*

Body Temperature: The Forgotten Variable

Hypothermia:

- *prolongs latency*

- *slows conduction*

Fever:

- *may shorten latency slightly*
- *increases noise*

*Temperature shifts milliseconds quietly—
and milliseconds are everything in ABR.*

*Ignoring temperature
is ignoring physiology.*

Anatomical & Physical Factors

Normal variations matter:

- *head size*
- *skull thickness*
- *ear canal geometry*
- *electrode distance*

These affect:

- *amplitude*
- *waveform clarity*
- *apparent asymmetry*

Not every asymmetry is neurological.

*Some are **geometrical**.*

Drugs: The Silent Modifiers

Drugs rarely abolish ABR.

*They **reshape it subtly**.*

Sedatives & Anesthetics

- *generally preserve ABR morphology*

- *may slightly prolong latency*
- *reduce muscle artifact*

*ABR is one of the safest tests under anesthesia—
but interpretation still needs context.*

Ototoxic Medications

- *may affect cochlear function*
- *change Wave I amplitude*
- *leave central conduction intact*

*Do not blame the brainstem
for cochlear pharmacology.*

Central Nervous System Drugs

- *anticonvulsants*
- *anesthetics*
- *sedatives*

These may:

- *alter neural synchrony slightly*
- *affect amplitude more than latency*

Small changes ≠ pathology.

*There is virtually no limit to the ways ABR waveforms can be altered
in disorders of the peripheral and central auditory system.*

*Abnormalities range from subtle latency deviations to complete
absence of a detectable response. Importantly:*

- *ABR abnormalities are **not mutually exclusive***
- *Multiple abnormal features may coexist in a single recording*

- ABR findings may be **dynamic**, changing over time or clinical state

This variability is especially evident in:

- Neuro-intensive care patients
- Intra-operative monitoring
- Acute neurologic or metabolic disturbances

Any attempt to categorize ABR abnormalities risks oversimplification.

*Therefore, classification schemes are useful only when combined with **flexible, patient-specific clinical judgment**.*

Framework for Interpreting Abnormal ABRs

Clinical interpretation of abnormal ABRs relies primarily on:

- ***Absolute latency analysis***
- ***Inter-wave latency analysis***
- ***Wave presence or absence***
- ***Morphology and repeatability***

All interpretations assume:

- Known stimulus parameters
- Known acquisition settings
- Awareness of patient factors such as age, gender, temperature, and medical status

Abnormal Absolute ABR Latency

Delayed Wave I

*The most common absolute latency abnormality is **prolonged wave I latency**, usually accompanied by proportional delay in later waves.*

*This pattern suggests **peripheral auditory dysfunction**.*

Key patterns:

- **Mild wave I delay**

Suggests high-frequency cochlear hearing loss

- **Marked wave I delay with preserved morphology**

Characteristic of conductive hearing loss or mixed loss

- **Absent wave I**

Common in moderate to severe sensory hearing loss above ~50 dB HL in the 1–4 kHz region

The distinction between conductive and sensory loss is critical:

- *Conductive loss delays wave I but preserves morphology at high intensities*
- *Sensory loss reduces wave I amplitude and distorts morphology*

Exceptions and Caveats

- *Extremely delayed wave I may occur with normal middle ear status*
- *Some sensory losses show near-normal wave I latency*
- **Neural auditory dysfunction** typically shows:
 - *Normal wave I latency*
 - *Abnormal latencies of later waves*

This pattern shifts diagnostic focus from the periphery to the brainstem .

Abnormal Inter-Wave Latency Patterns

Inter-wave latencies reflect relative neural conduction and synaptic timing within the auditory brainstem.

Mild Prolongation of I–V Interval

- *May reflect normal variation*
- *Must be interpreted in light of:*
 - *Age*
 - *Gender*
 - *Body temperature*
 - *Bilateral symmetry*

For example:

- *Mild bilateral prolongation is often normal in infants*
- *The same finding in a young adult female is more concerning*

Prolonged I–III Interval

This pattern strongly implicates pathology involving:

- *The auditory nerve*
- *The lower brainstem*
- *The cerebellopontine angle (CPA)*

Clinical correlations:

- ***Unilateral I–III delay***

Suggests CPA tumor or focal VIII nerve pathology

- ***Bilateral I–III delay***

Suggests diffuse brainstem dysfunction or, less commonly, bilateral VIII nerve disease

Prolonged III–V Interval

An isolated III–V delay with preserved wave I and III morphology suggests:

- *Rostral brainstem dysfunction*
- *Often associated with increased intracranial pressure*

- *Seen in hydrocephalus and dynamic neurologic compromise*

*This finding may reflect **serious neurologic disease** and warrants urgent correlation with imaging and clinical status.*

Global Inter-Wave Prolongation

Marked prolongation of all inter-wave latencies with poor morphology and reduced repeatability indicates:

- *Severe brainstem dysfunction*
- *Possible demyelinating disease in ambulatory patients*
- *Severe neurologic injury in critically ill patients*

Localization is limited, but the abnormality itself is diagnostically significant .

Missing ABR Components

Absent Wave V With Preserved Early Waves

A rare but striking pattern:

- *Clear waves I–IV*
- *Absent wave V*

This finding has been reported in:

- *Severe head injury*
- *Major neurologic disorders*

Clinical interpretation depends heavily on patient state and history.

Only Waves I and II Present

This pattern indicates:

- *Intact peripheral auditory function*
- ***Severe brainstem dysfunction***

In adults, it is often incompatible with long-term survival.

In infants, it may reflect profound hypoxic-ischemic injury.

Completely Absent ABR

*Before concluding pathology, **technical causes must be excluded**:*

- *Stimulus delivery failure*
- *Incorrect electrode placement*
- *Excessive artifact*
- *Equipment malfunction*

True absence of ABR may reflect:

- *Severe to profound hearing loss*
- *Advanced neurologic injury*
- ***Auditory Neuropathy Spectrum Disorder (ANSO)*** *when OAEs are preserved*

Advanced ABR Analysis Techniques

Overview

*Despite decades of research into sophisticated mathematical analysis of ABRs, **routine clinical practice remains dominated by time-domain visual inspection** of latency and amplitude.*

Advanced methods include:

- *Spectral (FFT) analysis*
- *Statistical detection algorithms*
- *Automated response detection*
- *Cross-correlation*
- *Machine-learning and pattern recognition*

To date, few have demonstrated **clear superiority** over expert visual analysis for diagnostic ABR interpretation .

Spectral Analysis of the ABR

FFT analysis confirms that ABRs contain energy in three main frequency regions:

- Below 150 Hz
- Approximately 500–600 Hz
- Approximately 900–1100 Hz

There is little energy above 2000 Hz.

However:

- The relationship between spectral content and specific ABR waves remains uncertain
- Short analysis times limit frequency resolution
- Windowing and filtering introduce artifacts

As a result, spectral analysis is primarily a **research tool**, not a routine clinical method.

Statistical Detection Measures (Fsp, Fmp)

The Fsp and Fmp statistics quantify signal-to-noise ratio.

Key principles:

- $F_{sp} \approx 1.0$ suggests no response
- $F_{sp} > 3.0$ is consistent with a true ABR
- These measures are widely used in newborn hearing screening

They are most useful for **response presence detection**, not detailed waveform interpretation .

Offline Waveform Manipulation

Digital Addition and Subtraction

Used to:

- *Enhance signal-to-noise ratio*
- *Eliminate stimulus artifact*
- *Combine replicated waveforms*
- *Derive horizontal electrode arrays*

Adding replicated waveforms is often preferable to recording a single long run.

Smoothing

Smoothing reduces high-frequency noise and improves visual clarity.

Limitations:

- *Does not create responses that are not already present*
- *Excessive smoothing reduces true wave amplitudes*

Use sparingly and cautiously.

Digital Filtering

Offline filtering can enhance wave visibility but carries risk.

Key cautions:

- *High-pass filtering above 150 Hz may eliminate infant ABRs*
- *Over-filtering low-frequency energy is a common cause of false-negative results*

*Filtering should **enhance**, not redefine, the waveform.*

Clinical Take-Home Message

Abnormal ABR patterns are diverse, dynamic, and context-dependent.

Reliable interpretation requires:

- *Careful latency analysis*

- Awareness of normal variability
- Integration of patient factors
- Skepticism toward oversimplified categories
- Preference for better recordings over excessive post-processing

Advanced analysis tools can assist detection but **do not replace expert clinical judgment.**

Perfect. This is a **foundational chapter**, and you were right to pause here.

What you shared is encyclopedic, but for a modern **clinical, teaching, and medico-legal reference**, it must be **re-organized into decision logic**, not a drug catalogue.

Below is a **clean, structured, Word-ready synthesis of Drugs and Troubleshooting in ABR Measurement**, faithful to the science, restraint, and nuance of your text, but transformed into **usable clinical guidance.**

I preserve the original caution that **statistical effects do not equal clinical significance** and I explicitly surface the rules clinicians must remember .

Auditory Brainstem Response

Drugs, Anesthesia, and Troubleshooting

PART I

Effects of Drugs on the Auditory Brainstem Response

Core Principle

A wide variety of drugs influence **cortical auditory evoked responses**, but **relatively few have clinically meaningful effects on the ABR**. In almost all cases:

- ABR is **far more resistant** to pharmacologic suppression than cortical responses
- No commonly used drug **completely abolishes** the ABR
- Many drug effects are **statistically significant in groups**, but **clinically insignificant in individuals**

The clinician's task is not to memorize drug names, but to understand **patterns of influence** and **when drug effects matter clinically**.

Ototoxic Drugs

Mechanism

Ototoxic drugs primarily damage:

- Outer hair cells
- Stria vascularis
- Cochlear metabolism

This produces **peripheral sensory hearing loss**, not neural conduction delay.

Risk Factors for Ototoxicity

Risk of cochlear damage increases with:

1. Impaired renal function
2. Treatment longer than 10 days
3. Concomitant ototoxic drugs, especially loop diuretics (e.g., furosemide)
4. Previous aminoglycoside exposure

5. *Advanced age*
6. *Pre-existing sensory hearing loss*
7. *Genetic susceptibility*

*Because of these interacting factors, **ototoxicity cannot be predicted with certainty** in individual patients .*

ABR Implications

- *Ototoxicity initially affects **high frequencies (>8000 Hz)***
- *Click and high-frequency tone burst ABRs are therefore **sensitive early indicators***
- *ABR is valuable when behavioral audiometry is not feasible, such as:*
 - *Premature infants*
 - *ICU patients*
 - *Oncology patients*

*ABR is used to **document auditory status**, not to certify “safe drug levels.”*

Sedatives and CNS Depressants

General Rule

Sedatives and hypnotics:

- *Suppress cortical responses*
- *Have **minimal or no effect on ABR***

This includes:

- *Benzodiazepines*
- *Barbiturates*
- *Opioid analgesics*

Chloral Hydrate (Historical Context)

- Long used for pediatric sedation
- Typical dose 50 mg/kg (max 1 g)
- ***No clinically meaningful effect on ABR***
- Markedly suppresses cortical responses

Its decline in use reflects workflow and safety considerations, not ABR validity .

Benzodiazepines and Opioids

- Diazepam, morphine, meperidine:
 - Do ***not alter ABR latency or amplitude***
 - Improve recordings by reducing muscle artifact

These drugs are often beneficial indirectly by improving signal-to-noise ratio.

Anesthetic Agents

Key Clinical Principle

ABR is the most anesthesia-resistant auditory evoked response.

Most anesthetics cause:

- Small latency prolongations (typically 0.15–0.5 ms)
- Little or no amplitude reduction
- No clinically meaningful elevation of ABR thresholds

Propofol

- Widely used in pediatric ABR under GA
- Produces ***dose-dependent latency prolongation***
- Amplitude is preserved or improved
- Threshold estimation remains reliable

- Reduced myogenic noise often **improves waveform quality**

Propofol is well suited for diagnostic ABR .

Volatile Anesthetics (Halothane, Isoflurane, Sevoflurane)

- Produce small, linear latency increases
- Effects are dose dependent
- Morphology is preserved
- Clinical interpretation remains valid

Important confounders:

- Body temperature
- Age
- Stimulus parameters

Narcotic Anesthetics

- Fentanyl, sufentanil:
 - Minimal ABR effects at clinical doses
 - Improve waveform quality via muscle suppression

Neuromuscular Blockers

- Do **not affect ABR generation**
- Often enhance recordings by eliminating muscle artifact
- ABRs remain fully interpretable during paralysis

Alcohol and Miscellaneous Drugs

- Acute alcohol intoxication:
 - Prolongs later wave latencies
- Chronic alcoholism:
 - Prolonged inter-wave latencies
 - Correlates with brain atrophy

- *Withdrawal:*
 - *Shortened latencies and increased amplitudes*

Hypothermia must always be excluded as a confounding factor.

Bottom Line on Drugs

Four clinically defensible rules apply:

1. *Drugs must always be **considered** in ABR analysis*
2. *Drug effects can **add to** other latency-influencing factors*
3. *ABR is far less affected than cortical responses*
4. ***Statistical drug effects ≠ clinical misinterpretation***

Troubleshooting ABR Measurement

Guiding Philosophy

The only serious problem in ABR measurement is the one that goes unrecognized.

*Troubleshooting is a **core clinical skill**, not a technical afterthought.*

Categories of Problems

1. *Predictable patient factors*
 - *Age*
 - *Hearing loss*
 - *Body temperature*
2. *Measurement errors*
 - *Electrode placement*
 - *Stimulus routing*
 - *Filter settings*
3. *Environmental interference*
 - *Electrical noise*

- *Equipment interaction*

Measurement Errors and Their Signatures

No Stimulus

- *Unplugged transducer*
- *Bone vibrator left disconnected*
- *Results in pure noise mistaken for late waves by inexperienced testers*

Wrong Stimulus Type

- *Tone burst left active instead of click*
- *Produces delayed responses without wave I*
- *Easily misinterpreted as pathology*

Artifact Rejection Disabled

- *Large muscle or movement artifact*
- *Spurious peaks mimic ABR waves*

Incorrect Filters or Analysis Time

- *AMLR filters applied to ABR*
- *Excessively long analysis window compresses waveform*
- *Produces misleading morphology*

Electrode Errors

Common Errors

- *Missing inverting electrode*
- *Reversed inverting and ground electrodes*
- *Contralateral electrode mistakenly used*
- *Inputs reversed at pre-amplifier*

Consequences

- *Cancellation of true ABR*
- *Inverted waveforms*
- *Apparent absence of response*

Electrode errors are the most dangerous cause of false diagnosis, including false profound hearing loss.

Preventing Electrode Errors

Practical safeguards:

- *Consistent color coding*
- *Fixed channel conventions*
- *Reproducible setup sequence*
- *Visual verification before recording*
- *Immediate suspicion when morphology is atypical*

Electrical Interference

Sources

- *Power line noise (50 or 60 Hz)*
- *ICU and OR equipment*
- *Transducer cables*
- *Long electrode leads*

Effective Solutions

Plan A

Identify and remove the source

Plan B

Minimize its effect:

- *Insert earphones*
- *Maximize distance between electrodes and transducer cables*

- *Short electrode leads*
- *Odd stimulus rates (e.g., 21.1/sec)*
- *Horizontal ear-to-ear electrode arrays in hostile environments*

What Does NOT Work

- *Notch filtering*
- *Blocking early waveform*
- *Excessive filtering*

*These often **destroy the ABR more than the noise.***

Training Strategy

Purposeful “mistake-making sessions” are strongly recommended:

- *Controlled environment*
- *Known normal subjects*
- *Systematic protocol violations*
- *Real-time observation of consequences*

*This is how clinicians develop **pattern recognition**, not by reading alone.*

Concluding Comments

Stimulus and acquisition parameters are controllable.

Patient cooperation and test environment often are not.

Expert ABR measurement depends on:

- *Evidence-based protocols*
- *Skilled analysis*
- *Rapid problem recognition*
- *Effective troubleshooting*

To paraphrase the original spirit of this chapter:

*You may not always record the ABR you want,
but with knowledge and persistence,
you can record the ABR you need.*

Key Points

- *Many ABR abnormalities are non-pathologic.*

Common Mistakes

- *Using adult norms in infants.*
- *Ignoring patient state.*

Report Writing

- *Recommend follow-up when maturation or state may change results.*

Medico-Legal Pitfalls

- *Permanent diagnoses based on transient conditions.*
- *Missing documentation of drugs or state.*

Final Clinical Message

Not every abnormal ABR belongs to disease.



CHAPTER

33

*Auditory Brainstem Response
Clinical Applications*

ABR is not performed because machines exist.

*It is performed because **decisions cannot wait.***

Every clinical application of ABR answers a different question.

*Every patient population **changes the meaning of the same waveform.***

*If you apply the same logic to all patients,
you are not being consistent—
you are being careless.*

ABR as a Clinical Tool: One Test, Multiple Missions

ABR serves different missions:

- *screening*
- *diagnosis*
- *threshold estimation*
- *neurodiagnostics*
- *medico-legal documentation*

The waveform does not change.

Infants and Young Children

In pediatrics, ABR often speaks first.

It may:

- *shape parental expectations*
- *trigger amplification*
- *influence CI pathways*

*Which makes **restraint mandatory**.*

NICU and High-Risk Infants

*NICU populations are **not small adults**.*

Common modifiers:

- *prematurity*
- *hypoxia*
- *hyperbilirubinemia*
- *ventilation*
- *medications*

ABR here is:

- *powerful*
- *fragile*
- *easily misinterpreted*

Protocols must be tailored.

Norms must be contextual.

Conclusions must be conditional.

Auditory Neuropathy Spectrum Disorder (ANSD)

ABR plays a defining role in ANSD:

- *absent or abnormal neural responses*
- *preserved cochlear microphonic*

*But ANSD diagnosis is **never ABR alone**.*

It requires:

- *polarity logic*
- *OAEs/CM confirmation*
- *clinical correlation*

*ABR here detects pattern,
not prognosis.*

Conductive, Mixed, and Sensorineural Loss

ABR helps:

- *differentiate type of loss*
- *support cross-check principles*
- *guide further testing*

But:

- *ABR does not replace tympanometry*
- *ABR does not define middle-ear pathology*

*Type differentiation is supportive—
not definitive—without integration.*

Neurodiagnostic Applications

ABR evaluates:

- *brainstem integrity*
- *neural conduction*
- *symmetry and interpeak timing*

Used in:

- *suspected tumors*
- *demyelinating disease*
- *brainstem lesions*

Here:

- *thresholds are irrelevant*
- *timing is everything*

*Mixing threshold logic into neurodiagnosis
destroys clarity.*

Adults Who Cannot Cooperate

ABR becomes essential in:

- *cognitive impairment*
- *altered consciousness*
- *medico-legal contexts*

But interpretation must:

- *acknowledge limitations*
- *avoid overreach*
- *document uncertainty*

*ABR supports decisions—
it does not replace clinical judgment.*

Special Populations: Syndromes & Complex Conditions

In:

- *genetic syndromes*
- *craniofacial anomalies*
- *developmental disorders*

ABR interpretation requires:

- *anatomical awareness*
- *modified expectations*
- *multidisciplinary integration*

Normal ABR does not equal normal function.

Abnormal ABR does not equal inevitable outcome.

ABR Threshold Estimation and Hearing Sensitivity

Auditory brainstem response testing plays a central role in estimating hearing sensitivity when behavioral measures are unreliable or unavailable. ABR threshold estimation provides an objective physiologic approximation of auditory sensitivity rather than a direct measure of perception. This chapter explains how ABR thresholds are derived, interpreted, and applied clinically.

Threshold estimation is one of the most common clinical uses of ABR. Understanding its principles helps clinicians:

- *Avoid over or underestimation of hearing loss*
- *Select appropriate stimuli for frequency specific assessment*
- *Integrate ABR findings with behavioral and functional data*
- *Make informed decisions regarding amplification and intervention*

Accurate threshold estimation requires both technical precision and clinical judgment.

Concept of ABR Threshold

An ABR threshold is defined as the lowest stimulus level at which a replicable neural response is identified. This level reflects neural detection of sound rather than conscious auditory perception.

Key points include:

- *ABR thresholds are electrophysiologic estimates*
- *They do not equal behavioral thresholds*
- *A predictable relationship exists between ABR and behavioral sensitivity*

Interpretation requires appropriate correction and correlation.

Role of Wave V in Threshold Estimation

Wave V is the primary marker used for ABR threshold estimation because it:

- *Persists at lower stimulus intensities*
- *Demonstrates consistent latency shifts with decreasing intensity*
- *Is more robust than earlier waves*

Near threshold, Wave V may be small and requires careful replication and analysis.

Stimulus Selection for Threshold Estimation

Click Stimuli

Click evoked ABR thresholds primarily reflect high frequency cochlear regions. They are useful for:

- *Estimating overall auditory sensitivity*
- *Screening for significant hearing loss*
- *Supporting neurologic assessment*

Clicks are limited in frequency specificity and should not be used alone for detailed audiometric profiling.

Tone Burst Stimuli

Tone burst ABR provides frequency specific threshold estimation by targeting restricted cochlear regions. Tone bursts are essential for:

- *Pediatric hearing assessment*
- *Hearing aid fitting decisions*
- *Cochlear implant candidacy evaluation*

Tone burst responses typically have longer latencies and require frequency specific normative data.

- *A compromise is always there between frequency specificity and sufficient synchronization*
- *Frequency specific stimuli tends to produce less synchronous response*

Effects of Hearing Loss on ABR Thresholds

Conductive Hearing Loss

Conductive pathology elevates ABR thresholds while preserving latency intensity relationships. Bone conduction ABR may assist in differentiating conductive from sensorineural components.

Sensorineural Hearing Loss

Cochlear hearing loss affects response visibility and threshold estimation accuracy. Severe losses may result in absent responses despite high stimulus levels.

Neural Hearing Disorders

In disorders affecting neural synchrony, ABR thresholds may not accurately reflect hearing sensitivity. ABR may be absent despite measurable behavioral responses.

Bone Conduction ABR

Bone conduction ABR assists in identifying conductive components of hearing loss. Clinical considerations include:

- *Limited maximum output*
- *Increased artifact*
- *Reduced frequency specificity*

Despite limitations, bone conduction ABR provides valuable diagnostic information.

Pediatric Considerations

ABR threshold estimation is particularly important in infants and young children. Key considerations include:

- *Maturation latency differences*
- *Need for age appropriate norms*
- *Emphasis on functional hearing estimation rather than exact thresholds*

Early estimation supports timely intervention.

*the **major clinical applications of the Auditory Brainstem Response (ABR)** with a primary focus on **children**, while also addressing selected adult applications where ABR continues to play a critical diagnostic or monitoring role.*

*In addition, the chapter summarizes **research-supported, evidence-based guidelines** for ABR measurement in specific patient populations.*

As outlined earlier in this book, the majority of contemporary clinical uses of ABR fall into five broad categories:

- *Infant hearing screening*

- *Diagnosis of auditory dysfunction in children*
- *Frequency-specific estimation of auditory thresholds in children*
- *Diagnosis of auditory dysfunction in adults*
- *Neurophysiological monitoring of patients at risk for auditory dysfunction*

The organization of this chapter follows this general framework.

However, the sequence of topics does not imply a hierarchy of importance or clinical prevalence. Each application serves distinct and essential clinical objectives, including early detection of hearing loss in infants, accurate diagnosis of auditory and neural dysfunction across the lifespan, and preservation of auditory function in patients undergoing intensive medical or surgical interventions.

Scope and Literature Perspective

*Since the first description of pediatric ABR measurement by Hecox and Galambos in 1974, an **extraordinary volume of literature** has accumulated describing ABR findings in children and adults with a wide range of auditory, neurologic, and systemic conditions. A comprehensive review of this literature would require multiple volumes and is well beyond the scope of a single chapter.*

*Accordingly, **selectivity was essential**. Decisions regarding inclusion and exclusion of material were guided primarily by one criterion:*

What practical information does the clinician need to diagnose auditory dysfunction and hearing loss using ABR?

Large bodies of literature are therefore condensed into focused summaries.

Inevitably, many valuable studies are not cited individually. This reflects limitations of scope, not lack of scientific merit.

Relationship to Earlier Editions

*This book represents a **radically revised and updated rendering** of earlier works, including Handbook of Auditory Evoked Responses (1992) and New Handbook of Auditory Evoked Responses (2007). Readers familiar with those volumes will immediately notice that many lengthy sections and even entire chapters are no longer included.*

Two major factors motivated this restructuring.

Impact of Technological Change

*First, **technology for ABR measurement and clinical application has evolved substantially** over the past several decades. Newborn hearing screening is a clear example.*

In earlier eras, audiologists performed newborn screening using full-featured ABR systems originally designed for diagnostic testing.

*Today, newborn hearing screening is largely automated, and the primary clinical responsibility of audiologists has shifted toward **diagnostic assessment of infants who do not pass screening**, rather than the screening process itself.*

*As a result, detailed operational descriptions of screening systems and extensive reviews of screening outcome studies have been intentionally omitted, allowing greater focus on **diagnostic ABR**, where clinical judgment and expertise remain essential.*

Impact of Information Accessibility

Second, the modern clinician operates in an information environment fundamentally different from that of earlier decades.

Ready access to the internet and powerful scientific search engines has transformed how clinicians obtain disease-specific knowledge.

*When confronted with a patient who has a specific diagnosis, clinicians can now rapidly access current, targeted literature through well-established databases such as **PubMed**, maintained by the National Library of Medicine. With a small number of carefully chosen search terms, clinicians can locate abstracts, full-text articles, and related references within minutes. Articles not immediately available online can often be obtained directly from corresponding authors in electronic format.*

*Given this reality, the purpose of this chapter is **not** to serve as an exhaustive catalog of ABR findings across every known disorder.*

*Instead, it aims to provide a **conceptual and clinical framework** that enables clinicians to interpret ABR findings intelligently and to seek additional information efficiently when needed.*

*the **current role of ABR in newborn and infant hearing screening**, followed by sections addressing the remaining major application areas:*

- Diagnosis of auditory dysfunction in pediatric populations*
- Frequency-specific estimation of auditory thresholds in infants and young children*
- Diagnosis of auditory dysfunction in adults*

- *Neurophysiological monitoring of patients at risk for auditory system compromise*

Across all sections, emphasis is placed on:

- *Clinical decision making*
- *Interpretation of ABR findings in context*
- *Evidence-based protocols*
- *Limitations and pitfalls*
- *Practical guidance rather than exhaustive citation*

This chapter is designed to help clinicians answer real clinical questions, not to overwhelm them with historical detail. The guiding philosophy is simple:

ABR is most powerful when used thoughtfully, interpreted cautiously, and integrated with other clinical information.

*The sections that follow build on the foundational material presented earlier in this book and apply it directly to **real patient populations and real clinical scenarios**.*

Take-Home Messages

- *Evoked responses are essential tools in pediatric audiology*
- *Interpretation must account for auditory system maturation*



CHAPTER

34

EHDI: Identification of Infant Hearing Loss with ABR

Early Hearing Detection and Intervention (EHDI)

is not a program.

*It is a **race against neuroplasticity**.*

ABR in EHDI is not about waves.

*It is about **windows**—*

windows that close quietly,

without apology.

Miss the window,

and no technology can fully reopen it.

Why ABR Is Central to EHDI

Infants cannot:

- *raise a hand*
- *repeat words*
- *cooperate*

ABR becomes:

- *the first objective voice*

- *the first diagnostic anchor*
- *the first determinant of timing*

In EHDI, ABR does not confirm hearing loss.

*It **initiates a trajectory**.*

That responsibility is enormous.

Screening vs Diagnostic ABR in EHDI: The Most Common Confusion

Screening ABR

- *fast*
- *automated*
- *risk-based*

It answers:

Is further evaluation needed?

*It does **not** answer:*

What is the degree or configuration of loss?

Diagnostic ABR

- *comprehensive*
- *frequency-specific*
- *replicated*
- *interpreted*

It answers:

What is the likely auditory status—and what should we do next?

Using screening logic to make diagnostic decisions

is the most shortcut in EHDI.

The EHDI Timeline: Why Timing Is Everything

The EHDI gold standard:

- ***Screen by 1 month***
- ***Diagnose by 3 months***
- ***Intervene by 6 months***

*ABR lives at the heart of the **3-month mark**.*

Delay here:

- *delays amplification*
- *delays language access*
- *delays cortical development*

Late diagnosis is not neutral.

*It is **biological loss**.*

ABR Strategy in Infant Identification

Effective EHDI ABR must include:

- *frequency-specific tone-burst ABR*
- *air and bone conduction when indicated*
- *masking when asymmetry exists*
- *polarity evaluation when ANSD is suspected*

*Click-ABR alone is **never sufficient***

for identification.

*Identification without frequency specificity
is partial truth.*

ANSD in EHDI: ABR as a Pattern Detector

EHDI is where ANSD often first appears.

ABR findings may show:

- *absent or severely abnormal waves*

- *preserved cochlear microphonic*

But:

- *ABR does not predict outcome*
- *ABR does not define management alone*

ANSD identification requires:

- *CM documentation*
- *OAEs*
- *longitudinal follow-up*

Labeling without context

creates panic—not care.

Common Mistakes

- *Relying on click-ABR alone.*
- *Using screening results as diagnosis.*
- *Delaying diagnostic ABR.*

Best-Practice Principles

- *Follow 1–3–6 (or earlier) EHDI timelines.*
- *Use frequency-specific diagnostic ABR.*
- *Integrate ABR with OAEs and clinical history.*



CHAPTER

35

EHDI: Follow-Up Diagnostic ABR Assessment

Screening opens the door.

*Follow-up diagnostic ABR **decides what happens next.***

This is not a repeat test.

This is not confirmation theater.

*This is the moment where uncertainty must be **disciplined**,
and hesitation must be **intentional—not accidental.***

In EHDI, the follow-up ABR is where children are either:

- ***found in time**, or*
- ***lost politely.***

What “Follow-Up” Really Means in EHDI

Follow-up diagnostic ABR is not:

- *repeating the screen*
- *running the same protocol again*
- *hoping for a clearer waveform*

It is:

- *escalation in **depth***

- escalation in **specificity**
- escalation in **clinical responsibility**

If the follow-up ABR does not change the level of certainty, it has failed—no matter how clean the waves look.

The Purpose of Follow-Up ABR

*The follow-up diagnostic ABR must answer **three non-negotiable questions**:*

- 1. **Is hearing loss present?***
- 2. **What is the degree and configuration?***
- 3. **What action must follow—now?***

Anything short of this is data collection, not diagnosis.

Timing: The Quiet Enemy of EHDI

Follow-up ABR must happen:

- *early enough to preserve neuroplasticity*
- *late enough to allow stable acquisition*

Delay for “better cooperation”

*often becomes delay with **biological cost**.*

In EHDI, perfect conditions are not a prerequisite.

Timely, defensible information is.

Core Components of a Proper Follow-Up ABR

A legitimate follow-up diagnostic ABR includes:

- ***Frequency-specific tone-burst ABR***
- ***Air and bone conduction when indicated***
- ***Masking in asymmetric cases***
- ***Replication at each critical level***

- ***Polarity analysis when ANSD is suspected***

Click-only follow-up ABR

is not follow-up—it is avoidance.

Threshold Estimation: Precision Without Illusion

Follow-up ABR thresholds are:

- *estimates*
- *frequency-bound*
- *correction-dependent*

*They are **good enough to act**,*

but never perfect enough to overstate.

The goal is not audiometric beauty.

*The goal is **clinical direction**.*

ANSD Revisited: Follow-Up Is Where It Becomes Clear

Many ANSD patterns:

- *declare themselves clearly only on follow-up*
- *evolve with maturation*
- *require repeated polarity-controlled recordings*

The follow-up ABR is where:

- *artifact is excluded*
- *CM is confirmed*
- *assumptions are tested*

ANSD is not diagnosed by absence.

*It is diagnosed by **pattern consistency over time**.*

When Follow-Up ABR Is “Inconclusive”

“Inconclusive” is not failure

*if it is **honestly reached**.*

Acceptable reasons for inconclusiveness:

- *unstable patient state*
- *borderline thresholds*
- *conflicting objective results*

Unacceptable reasons:

- *rushed protocol*
- *incomplete frequencies*
- *fear of making a decision*

If inconclusive, the report must:

- *say why*
- *say what’s next*
- *say when*

Silence is not neutrality.

It is abandonment.

Follow-Up ABR and the Next Clinical Step

The follow-up ABR must point clearly toward:

- *amplification trial*
- *further objective testing*
- *behavioral confirmation*
- *medical referral*

*If the report does not move the child forward,
it has failed its ethical role.*

Neonatal Hearing Screening Protocols

Screening

It is the process of applying ,to a large number of individuals, certain rapid, simple measurement that will identify those individuals with high probability of hearing loss.

Neonatal Hearing screening

- *The process through which preliminary hearing screening is provided Should be*
- *Rapid*
- *Simple*
- *Reliable*
- *Economic*

Why Should we Screen for hearing

- *Number one birth deficit.*
- *If Early & appropriate intervention (< 6 months old) children will develop speech, language & social skills as normal peers.*
- *Availability of acceptable technologies for effective screening.*

Impact of hearing loss in children

-Delayed Speech & Language Development

= Communication problem

Learning Problem = Scholastic underachievement

Social & Behavioral problem = Withdrawal & or Aggression

Joint Committee 2007

- *The Joint Committee on Infant Hearing (JCIH) endorses early detection of and intervention for infants with hearing loss.*

The goal of early hearing detection and intervention (EHDI) is to maximize linguistic competence and literacy development for children who are deaf or hard of hearing.

Without appropriate opportunities to learn language, these children will fall behind their hearing peers in communication, cognition, reading, and social-emotional development. Such delays may result in lower educational and employment levels in adulthood.

- *To maximize the outcome for infants who are deaf or hard of hearing, the hearing of all infants should be (RECOMMENDATIONS) screened at no later than 1 month of age.*

Pre-requisites for Successful Program

- *Definition of the program goals*
- *Selection of the target population*
- *Selection of test(s)*
- *Establishment of the normative data*
- *Objective Pass/ fail criteria*
- *Arrangement for the diagnostic follow -up*
- *Good contact with appropriate referrals*

Types of neonatal hearing screening

1. Universal: all live births

(low + high risk)

2. Targeted: high risk population

Targeted screening (Joint Cometee 2007)

High risk registers:

- *Family history*
- *Congenital infections e.g. rubella, syphilis*
- *Craniofacial anomalies*
- *Low birth weight (< 1500gm)*
- *Hyperbilirubemia.*
- *Ototoxicity.*
- *Bacterial meningitis.*
- *Severe depression of Apgar score.*
- *Prolonged mechanical ventilation.*
- *NICU infants.*
- *Suggested syndrome with hearing loss*

When to screen?

Joint Committee on Infant Hearing (2007)

- *Universal screening within 1 month of age.*
- *Complete diagnostic evaluation by 3 months.*
- *Intervention maximally by the age of 6 months.*

Methods of neonatal screening

1-Subjective

2-Equipment

Screening

OAEs

ABR

OAEs & ABR

ASSP

Frequently Used Protocols

- *Combined AABR + TEOAE in the first 48 hours after birth*
- *Rescreen before discharge from hospital in case of failed response*
- *Full diagnostic protocols at the age of 3 months for failed cases*

AABR

- *The only method to detect neural HL*
- *Absence of ABR to 30 or 35 dB nHL, 100 μ s clicks reveals mild and more severe hearing loss*
- *Procedure:*

For automated ABR testing, 3 surface electrodes should be placed on the head, 1 on each mastoid and 1 on the high forehead.

Insert receiver or Cup electrode is inserted into the ear canal,.

ABR in Neonatal Screening



Figure 33.1 congenital atresia ABR in Neonatal Screening.

- *Alternating-polarity clicks were 100 microseconds in duration and were presented at a rate of 37.1 per second, at 35 dB normal hearing level. The automated ABR responses is low-pass filtered at 1500 Hz and high-pass filtered at 100 Hz.*
- *At least 1000 sweeps is required for the automated ABR average, but as many as 2 trials of 6144 sweeps might have been recorded. The presence of a response is determined with a patented signal-detection algorithm, point-optimized, variance ratio, and a pass or refer result is assigned.*

ABR in neonatal hearing screening

- *Pass/fail criteria (Barker et al., 2000):*

A reliable ABR wave V evoked by 35 dBHL

Pass.

- *Screening parameter: detection of Wave V*
- *Automated detection of ABR – Automated ABR (AABR)*
- *Statistical technique based universal – non age-specific*
- *Template-based are age-specific, typically 0-2 months*

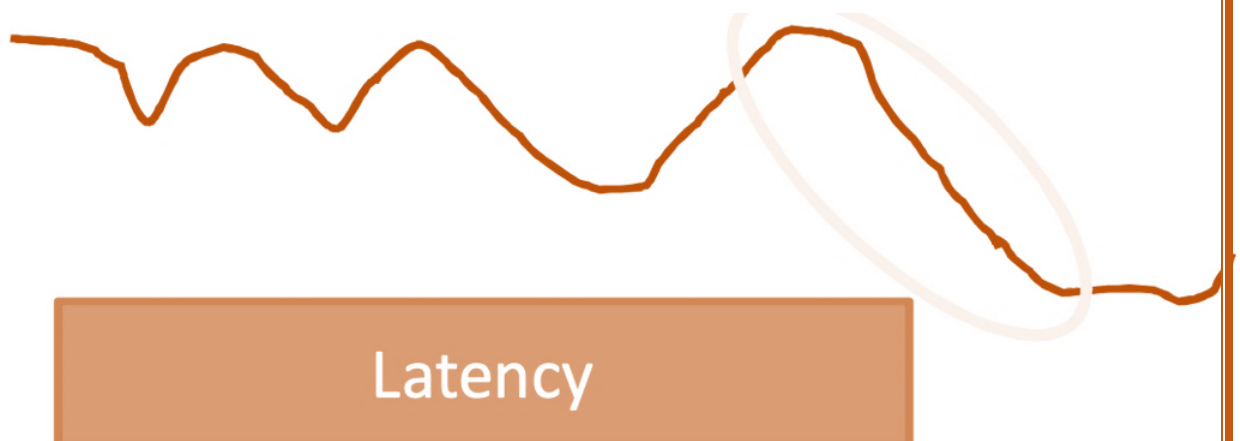


Figure 33.2 ABR in neonatal hearing screening.

Advantages of ABR for neonatal hearing screening

- *Objective screen for auditory function.*
- *Measure brain stem integrity.*
- *Recommended to detect ANSD in NICU*
- *Limited interference with ear canal debris /middle ear effusion.*
- *AABR: - Less time consuming.*
- *High specificity.*
- *Portable.*
- *Easily performed*

Disadvantages of ABR for neonatal hearing screening

- *Needs elaborate equipment, electrodes,time,etc...*
- *Effect of maturation.*
- *Interference with equipment of the NICU*

Two stage OAE-ABR screening

- *An OAE test followed by ABR screen for those infants not passing the OAE screen.*
- *100 % sensitivity.*
- *Low referral rates of 3%.*
- *Detects auditory neuropathy cases.*

ABR in Neonates (3 peaks only)

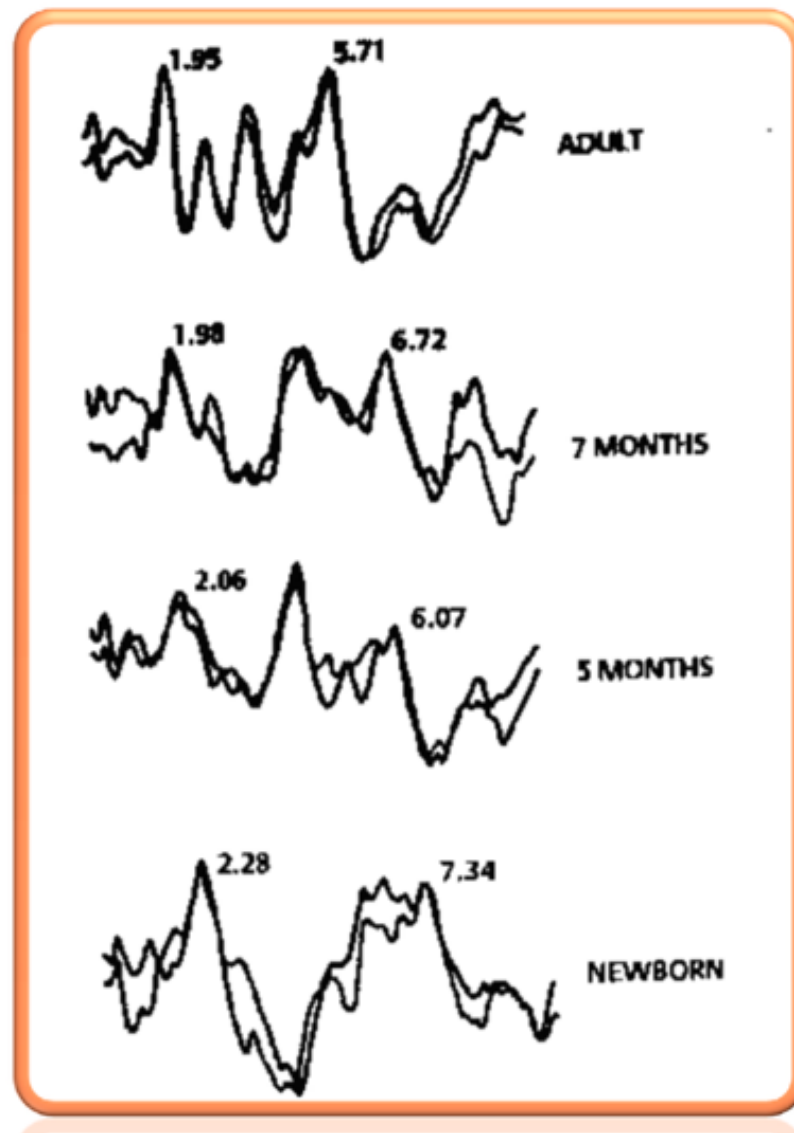


Figure 33.3 ABR in Neonates (3 peaks only).

ABR in neonatal hearing screening

Wave I amplitude is larger than in adults

(Recording electrode is closer to the cochlea due to the smaller head size of infants.)

The ***latencies*** of the ABR waveform I, V and I-V interval components are ***longer*** than adults

(Decreased throughout the maturation of the cochlea and brainstem.)

Should correct by ***18-24 months*** of age.

ABR in Neonates

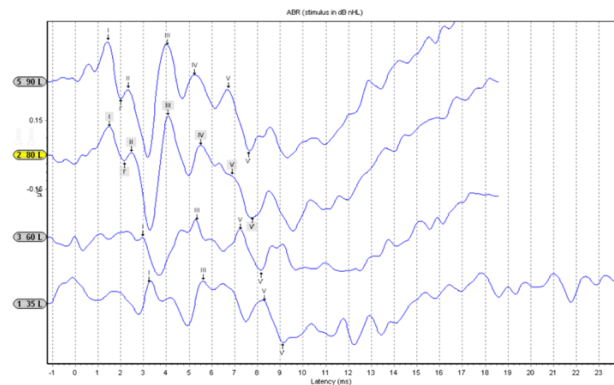


Figure 33.4 ABR in Neonates.

- ABR is integral part of Neonatal hearing screening
- It must be applied to all NICU children

Key Points

- Frequency-specific testing is mandatory.

Common Mistakes

- Using vague conclusions.

Red Flags

- No clear recommendation for next steps.

The most expensive ABR is the one done too late.



CHAPTER

36

Pediatric Applications: Peripheral Auditory Disorders

In pediatrics, peripheral auditory disorders are never “simple.”

*They are **simple-looking**.*

The danger is not missing pathology.

*The danger is **oversimplifying it**.*

ABR in children does not diagnose ears.

*It **interprets vulnerability** in a developing system.*

What “Peripheral” Really Means in Children

Peripheral auditory disorders involve:

- *outer ear*
- *middle ear*
- *cochlea*
- *auditory nerve (pre-synaptic)*

But in children:

- *boundaries are blurred*
- *maturation interferes*
- *middle ear status changes fast*

Calling something “peripheral” in pediatrics is a hypothesis—not a conclusion.

Conductive Hearing Loss: The Great Mimicker

What ABR Often Shows

- *delayed absolute latencies*
- *preserved interpeak intervals*
- *waveform morphology relatively intact*

The Trap

Delayed waves $\neq$ neural delay.

In children:

- *otitis media*
- *effusion*
- *canal debris*

*can **shift everything** without touching the brainstem.*

ABR supports conductive diagnosis

*only when **bone conduction logic is applied correctly.***

Sensorineural Hearing Loss: Degrees Matter

In pediatric SNHL:

- *ABR helps estimate severity*
- *frequency-specific data guides intervention*

But:

- *ABR does not predict speech outcomes*
- *ABR does not replace behavioral follow-up*

*Threshold estimation is a **starting point**,
not the finish line.*

Cochlear vs Neural: Where Mistakes Are Born

Absent or poor Wave I:

- *may suggest cochlear synaptopathy*
- *may reflect stimulus or electrode issues*

Later waves without Wave I

do not automatically mean neural pathology.

In pediatrics,

cochlear issues often masquerade as neural ones.

Auditory Neuropathy Spectrum Disorder (Peripheral–Neural Interface)

ANSD sits at the border.

ABR findings:

- *absent or severely abnormal waves*
- *preserved CM*

But in children:

- *ANSD patterns may evolve*
- *maturation may improve synchrony*
- *outcomes are unpredictable*

*ABR identifies the **pattern**,*

not the prognosis.

Best-Practice Principles

- *Integrate ABR with tympanometry, OAEs, and history.*
- *Use BC ABR when CHL is suspected.*



CHAPTER

37

***Pediatric Applications: Peripheral Auditory Disorders
Outer and Middle Ear Pathology – Cochlear Pathology***



In children, peripheral auditory pathology is not a location.

*It is a **moving target**.*

Outer ear changes.

Middle ear fluctuates.

Cochlear pathology hides behind both.

ABR here is not a detector.

*It is a **discriminator**—*

between temporary obstruction,

and permanent sensory damage.

Outer Ear Pathology: The Simplest Cause, the Most Ignored

Common Pediatric Outer Ear Factors

- *vernix*
- *debris*
- *narrow or collapsing canals*
- *probe obstruction*

ABR Impact

- *elevated thresholds*
- *delayed absolute latencies*
- *preserved interpeak intervals*

The Trap

Outer ear problems rarely look dramatic.

*But they can **invalidate the entire test**.*

ABR that ignores the ear canal

is blind before it starts.

Middle Ear Pathology: The Master of Deception

*Middle ear disease is the **number one confounder** in pediatric ABR.*

Common Conditions

- *otitis media with effusion*
- *negative middle ear pressure*
- *recurrent infections*
- *predict benefit*
- *define final management alone*

Frequency-Specific ABR: Non-Negotiable in Cochlear Loss

Click ABR is blind to configuration.

Cochlear pathology demands:

- *tone-burst ABR*
- *low-frequency assessment*
- *correction factors*

Without frequency specificity,

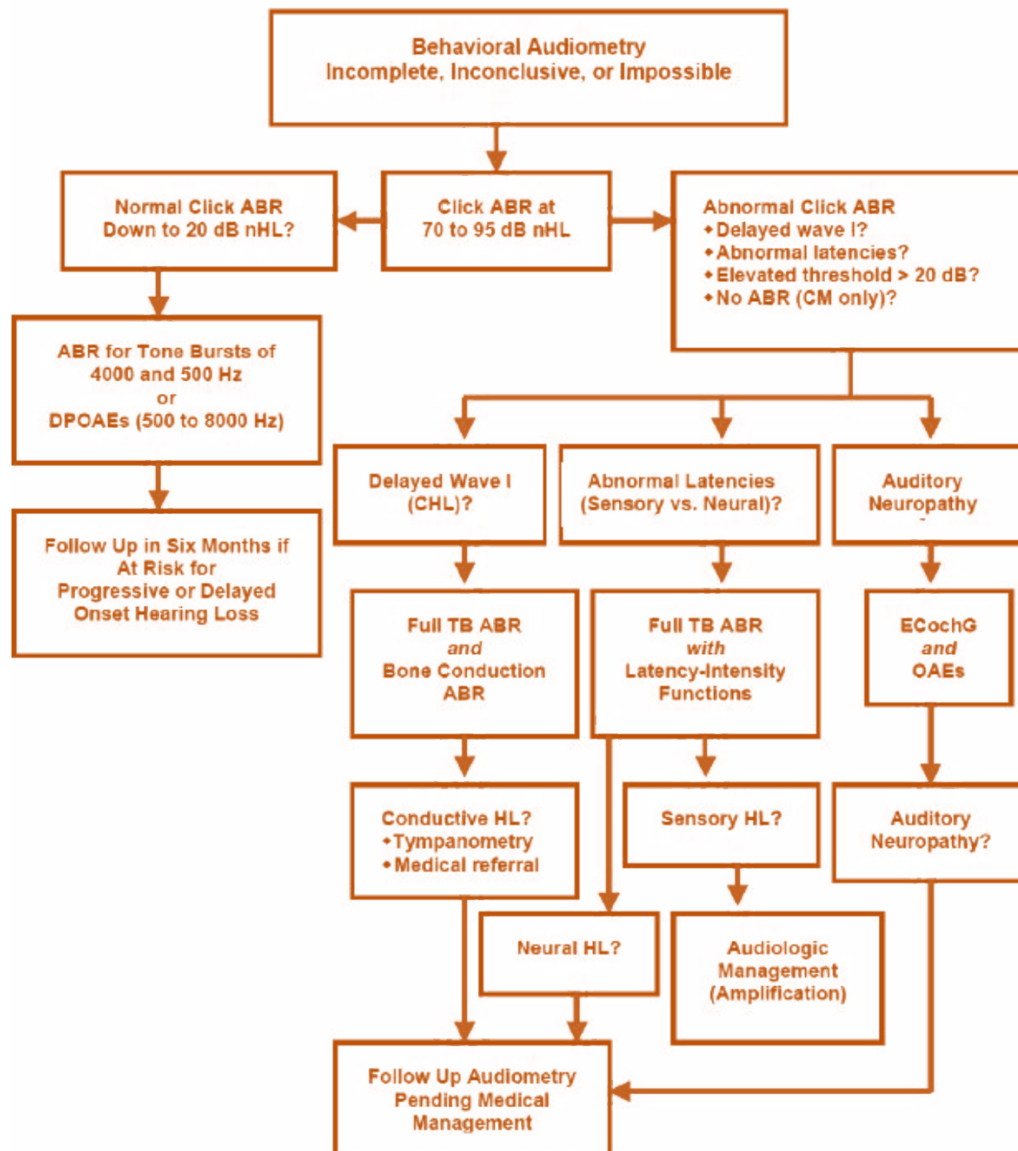
intervention decisions float without anchor.

Common Mistakes

- Ignoring otoscopy and tympanometry.
- Skipping BC ABR.

Red Flags

- Permanent diagnosis with abnormal middle ear status.



Flowchart 35.1.



CHAPTER

38

*Pediatric Applications:
Estimation of Auditory Thresholds*



In children, thresholds are not numbers.

*They are **decisions in disguise**.*

Every estimated threshold can:

- *open access to sound*
- *delay language*
- *trigger amplification*
- *push toward cochlear implantation*

*Which means threshold estimation in pediatrics
is not technical work.*

*It is **ethical work**.*

What “Estimation” Really Means

ABR thresholds are:

- ***estimates**, not truths*
- ***frequency-bound**, not global*
- ***context-dependent**, not absolute*

*They are good enough to act—
but never good enough to boast.
If you treat ABR thresholds as audiometry,
you will eventually hurt someone.*

Why Pediatric Threshold Estimation Is Different

Children:

- *cannot cooperate reliably*
- *have immature auditory systems*
- *have unstable middle ears*
- *change fast*

Which means:

- *precision is limited*
- *confidence must be earned*
- *humility is mandatory*

In pediatrics,

overconfidence is more than uncertainty.

Click ABR vs Frequency-Specific Thresholds

Click ABR:

- *reflects high-frequency synchrony*
- *is not frequency-specific*
- *cannot define configuration*

Tone-burst ABR:

- *estimates thresholds by frequency*
- *supports hearing-aid fitting*
- *guides early intervention*

*Using click thresholds to guide amplification
is not simplification.*

It is distortion.

Tone-Burst ABR: The Backbone of Estimation

Proper pediatric threshold estimation requires:

- *multiple frequencies*
- *descending intensity steps*
- *replication near threshold*
- *correction factors*

Tone-burst ABR is slower.

But speed has never built language.

Correction Factors: Where Many Clinicians Get Lost

*ABR thresholds are **not behavioral thresholds**.*

They require:

- *frequency-specific correction factors*
- *age-appropriate norms*
- *awareness of transducer effects*

*Ignoring correction factors
creates “normal-looking” audiograms
that do not match reality.*

Correction is not optional.

It is the bridge to truth.

Air vs Bone Conduction in Threshold Estimation

Without BC ABR:

- *conductive components are missed*

- *degree is overestimated*
- *intervention is misdirected*

BC ABR:

- *refines type*
- *protects from overfitting*
- *prevents premature labeling*

Threshold estimation without BC

is incomplete by design.

Near-Threshold Recording: Where Errors Are Born

Near threshold:

- *waveforms are small*
- *noise competes*
- *confirmation is harder*

Rules here are strict:

- *replicate*
- *slow the rate*
- *avoid aggressive filtering*
- *accept “no response” honestly*

*Inventing thresholds is worse
than admitting uncertainty.*

Low Frequencies: The Most Neglected Truth

Low-frequency thresholds:

- *matter for speech perception*
- *are hardest to record*
- *are most often skipped*

Skipping low frequencies:

- *biases configuration*
- *distorts fitting*
- *misleads counseling*

*If you don't measure them,
don't pretend you know them.*

Estimating Severe-to-Profound Loss

In severe losses:

- *ABR may disappear early*
- *CM may persist*
- *estimates become coarse*

Here ABR should:

- *define range, not point*
- *support CI candidacy logic*
- *integrate with ASSR and OAEs*

False precision here is unethical.

Most pediatric intervention errors

*start with **bad threshold estimation**:*

- *overfitting*
- *underfitting*
- *delayed decisions*

This chapter exists to remind you:

thresholds guide futures.

Key Points

- *ABR thresholds are estimates, not absolutes.*

- *Frequency-specific testing is mandatory.*
- *Correction factors are essential.*
- *BC ABR refines degree and type.*

Common Mistakes

- *Using click ABR for fitting decisions.*
- *Ignoring correction factors.*
- *Skipping low frequencies.*
- *Forcing thresholds from noise.*



CHAPTER

39

*Pediatric Applications:
Neural and Central Auditory Disorders*



In children, neural and central auditory disorders are never obvious.

*They are **subtle, evolving, and to oversimplify.***

ABR here is not looking for loss.

*It is looking for **integrity, timing, and survival of synchrony.***

And the most important rule:

Not every abnormal ABR in a child is a neural disorder.

But every neural disorder deserves ABR respect.

What “Neural and Central” Means in Pediatrics

Neural and central disorders involve:

- *auditory nerve*
- *brainstem pathways*
- *central auditory structures*

But in children:

- *myelination is ongoing*
- *synchrony is fragile*

- *compensation is possible*

Which means:

- *patterns evolve*
- *early findings may normalize*
- *late findings may emerge silently*

Static thinking here is malpractice.

Why Neural Diagnosis in Children Is High-Risk

Labeling a child with a neural or central disorder:

- *changes parental expectations*
- *alters educational planning*
- *shapes lifelong identity*

Which means:

the burden of proof is higher than in adults.

ABR findings must be:

- *pattern-based*
- *replicated*
- *contextualized developmentally*

Confidence must be earned slowly.

Auditory Neuropathy Spectrum Disorder (ANSD)

ANSD is the most misunderstood pediatric neural diagnosis.

Core ABR Pattern

- *absent or grossly abnormal neural waves*
- *preserved cochlear microphonic*
- *often present OAEs (early)*

But in children:

- *ANSD may improve*
- *ANSD may worsen*
- *ANSD may fluctuate*

*ABR identifies the **pattern**.*

*Time reveals the **trajectory**.*

The ANSD Trap

Common errors:

- *diagnosing ANSD from a single test*
- *ignoring polarity logic*
- *predicting speech outcomes from ABR alone*

ANSD is not a sentence.

*It is a **follow-up diagnosis**.*

Brainstem Conduction Disorders

Typical ABR Clues

- *prolonged interpeak intervals*
- *interaural asymmetry*
- *rate-sensitive degradation*

But Before You Diagnose

Exclude:

- *age-related delay*
- *middle ear effects*
- *stimulus parameter bias*

In pediatrics,

delayed does not mean diseased—

*unless it persists **appropriately challenged**.*

Prematurity and Hypoxic Injury

Premature infants often show:

- *delayed latencies*
- *immature morphology*
- *poor early synchrony*

These findings may:

- *normalize with maturation*
- *partially improve*
- *reveal vulnerability later*

*ABR here is **prognostic-sensitive but prediction-limited**.*

Central Auditory Processing: What ABR Can and Cannot Do

ABR:

- *evaluates brainstem integrity*
- *does not diagnose CAPD*
- *does not predict higher auditory processing*

Using ABR to “rule in” CAPD

is category confusion.

*ABR rules out **gross neural dysfunction**,
not cortical listening difficulty.*

Syndromic and Genetic Conditions

In syndromes:

- *anatomy may distort waveforms*
- *timing norms may not apply*
- *patterns may be asymmetric*

ABR interpretation must:

- *integrate genetics*
- *integrate imaging*
- *integrate development*

Normal ABR $\neq$ normal auditory function.

Abnormal ABR $\neq$ inevitable disability.

When ABR Is Abnormal but the Child Is Functioning

This is the hardest scenario.

Possible explanations:

- *compensation*
- *plasticity*
- *evolving pathology*
- *testing artifact*

In pediatrics,

function matters as much as physiology.

*ABR must never be interpreted in isolation from behavior—
even if behavior comes later.*

Common Mistakes

- *Ignoring maturation effects.*

Red Flags

- *ABR-based CAPD diagnoses.*



CHAPTER

40

Special Populations and Clinical Challenges



Not all patients fit standard testing protocols.

Medical complexity, neurologic involvement, developmental limitations, and environmental factors often require modification of auditory evoked response procedures and interpretation strategies.

This chapter addresses how evoked responses are applied in special populations and how clinicians navigate challenging clinical scenarios while maintaining diagnostic accuracy.

Special populations are at higher risk for diagnostic error.

This chapter helps clinicians:

- *Adapt evoked response protocols to complex clinical conditions*
- *Recognize when standard interpretation rules do not apply*
- *Avoid misattributing non auditory factors to hearing pathology*
- *Maintain evidence based decision making under challenging conditions*

Clinical flexibility grounded in physiologic understanding is essential.

Patients With Multiple Disabilities

Individuals with multiple developmental or medical disabilities often cannot participate in behavioral audiometry.

Evoked responses provide objective insight into auditory system integrity. Key considerations include:

- *Increased susceptibility to physiologic noise*
- *Atypical neural timing unrelated to hearing status*
- *Need for conservative interpretation*

Results must be integrated with the overall developmental and medical profile.

Neurologic and Neurodevelopmental Disorders

Neurologic conditions may alter evoked responses independently of auditory sensitivity.

Examples include:

- *Cerebral palsy*
- *Seizure disorders*
- *Neurodegenerative diseases*
- *Central nervous system infections*

ABR abnormalities in these patients may reflect central dysfunction rather than peripheral hearing loss.

Premature and Medically Fragile Infants

Premature infants present unique challenges due to physiologic instability and immature auditory pathways.

Considerations include:

- *Prolonged latencies due to delayed myelination*
- *Increased vulnerability to noise and artifact*

- *Need for careful timing of assessment*

Interpretation must distinguish maturation from permanent dysfunction.

Auditory Neuropathy Spectrum Disorder

Auditory neuropathy represents a distinct diagnostic category characterized by disrupted neural synchrony.

Typical findings include:

- *Absent or severely abnormal ABR*
- *Preserved cochlear microphonics*
- *Variable behavioral hearing thresholds*

Evoked responses are essential for diagnosis but limited for threshold estimation in this population.

Suspected Nonorganic Hearing Loss

In cases where behavioral responses are inconsistent or exaggerated, evoked responses provide objective verification of auditory pathway function. Clinical considerations include:

- *Using evoked responses to support, not confront, patients*
- *Avoiding definitive statements without corroborating evidence*
- *Communicating results carefully*

Objective testing should reduce conflict rather than escalate it.

Hospital and Intensive Care Settings

Evoked response testing in inpatient settings presents additional challenges:

- *Electrical interference from medical equipment*
- *Physiologic instability*

- *Limited control over testing environment*

Despite these challenges, valid recordings are achievable with careful protocol adaptation.

Cultural and Communication Barriers

Language and cultural factors may limit the reliability of behavioral testing. Evoked responses provide an objective alternative that reduces dependence on patient communication, supporting equitable diagnostic access.

Ethical Responsibilities in Special Populations

Testing vulnerable populations carries ethical responsibility.

Clinicians must:

- *Avoid overdiagnosis*
- *Clearly communicate uncertainty*
- *Ensure recommendations are proportional to the strength of evidence*
- *Consider the long term impact of diagnostic labels*

Ethical practice is inseparable from technical expertise.

Red Flags

- *Poor data quality interpreted as pathology*
- *Diagnostic conclusions without multidisciplinary input*



CHAPTER

41

Adult Applications: Middle Ear Disorders

In adults, middle ear disease does not ask for attention.

*It **distorts quietly**.*

ABR here is not hunting pathology.

*It is **protecting interpretation**—*

*from being fooled by a conductive system
that shifts timing without touching neurons.*

The mistake is not missing middle ear disease.

*The mistake is **calling it neural**.*

Why Middle Ear Disorders Matter in Adult ABR

Adult middle ear pathology:

- *is common*
- *is often underestimated*
- *alters latency more than morphology*

ABR does not see the middle ear directly.

*It sees **the consequences of impedance**.*

*If you ignore the middle ear,
ABR will mislead you politely.*

Common Adult Middle Ear Conditions Affecting ABR

- *Otitis media with effusion*
- *Negative middle ear pressure*
- *Tympanosclerosis*
- *Ossicular fixation (e.g., otosclerosis)*
- *Post-surgical middle ear changes*

*Each can **delay absolute latencies**
while preserving interpeak intervals.*

*This pattern is classic—
and commonly misread.*

The Classic Conductive ABR Pattern in Adults

Typical findings:

- *prolonged absolute latencies (I, III, V)*
- *relatively normal interpeak intervals*
- *preserved morphology*
- *elevated thresholds*

This is not subtle.

*But it becomes dangerous
when interpreted without context.*

Otosclerosis: The Silent Distorter

In otosclerosis:

- *cochlear function may be intact*
- *middle ear mechanics are altered*

ABR may show:

- *latency shifts*
- *reduced Wave I clarity*
- *normal interpeaks*

Calling this neural delay

is a diagnostic error with consequences.

Bone conduction logic

is your defense.

Post-Surgical and Chronic Middle Ear States

Adults with:

- *tympanoplasty*
- *mastoid surgery*
- *chronic disease*

may show:

- *atypical wave morphology*
- *altered amplitudes*
- *asymmetries unrelated to brainstem pathology*

ABR interpretation must:

- *respect surgical history*
- *avoid normal-expectation bias*

A “non-standard ear”

creates non-standard ABR.

Bone Conduction ABR in Adults: Still Relevant

BC ABR is often skipped in adults.

That is a mistake.

BC ABR:

- *confirms conductive components*
- *prevents neural overdiagnosis*
- *refines degree estimation*

In adults, BC ABR is not pediatric.

*It is **protective**.*

Middle Ear Disorders vs Retrocochlear Suspicion

The critical fork:

- *delayed absolute latencies with normal interpeaks → think middle ear*
- *prolonged interpeaks, asymmetry, rate sensitivity → think neural*

Mixing these logics

creates false tumors and missed reassurance.

Threshold Estimation: Handle with Care

In adult middle ear disease:

- *ABR thresholds overestimate cochlear loss*
- *correction requires BC and tympanometry*

Using AC ABR thresholds alone

overstates severity

and misguides amplification decisions.

Why Adults Are Not “Easier” Than Children

Adults:

- *compensate better*
- *complain less*
- *present later*

Which means:

- *pathology hides longer*
- *ABR interpretation must be sharper*

Assuming adult stability

is how conductive disease fools experts.

Common Mistakes

- *Ignoring tympanometry and otoscopy.*

Ethics

- *Overdiagnosis causes anxiety and unnecessary imaging.*



CHAPTER

42

*Adult Applications:**Neural and Central Auditory Disorders*

In adults, neural and central auditory disorders are feared more than they are found.

*And that fear is exactly why ABR must be **disciplined, cold, and honest.***

ABR here is not reassurance by beauty.

*It is reassurance by **logic.***

The enemy is not pathology.

*The enemy is **misinterpretation under anxiety.***

What “Neural and Central” Means in Adults

In adults, neural and central disorders involve:

- *auditory nerve integrity*
- *brainstem conduction*
- *inter-nuclear timing*

Unlike children:

- *maturation is complete*

- *plasticity is limited*
- *abnormalities are more stable*

Which means:

- *persistent abnormalities matter*
- *patterns carry weight*
- *false positives are common if logic slips*

*Adult ABR demands **higher precision, not higher suspicion.***

Why ABR Still Matters in the MRI Era

ABR is not obsolete.

It answers questions MRI cannot:

- *functional integrity*
- *physiological timing*
- *bilateral comparison under identical conditions*

MRI sees structure.

*ABR sees **consequence.***

ABR does not replace MRI.

*It **protects it from misuse.***

Classic Neural ABR Patterns in Adults

1. Prolonged Interpeak Intervals

- *I–III, III–V, or I–V delay*
- *often asymmetric*

This suggests impaired conduction

only after conductive and parameter causes are excluded.

2. Asymmetry Between Ears

- *latency or waveform differences*

- *under identical stimulus conditions*

*True asymmetry is one of the strongest neural clues—
but only if the setup is clean.*

3. Rate-Sensitive Degradation

- *normal responses at slow rates*
- *latency prolongation or waveform collapse at fast rates*

Rate challenges neural reserve.

Conductive disease does not fail this test.

4. Poor Replication Despite Adequate SNR

- *instability across runs*
- *morphology inconsistency*

*This often reflects neural dysfunction—
after excluding noise and setup issues.*

Vestibular Schwannoma: The ABR Reality

*ABR is **not a tumor detector**.*

*It is a **tumor screener**.*

ABR may show:

- *delayed Wave V*
- *prolonged interpeaks*
- *interaural asymmetry*

But:

- *small tumors may escape ABR*
- *normal ABR does not rule out pathology*

ABR reduces unnecessary MRI.

It does not eliminate justified MRI.

Demyelinating Disease

In demyelination:

- *interpeak intervals prolong*
- *wave morphology degrades*
- *rate sensitivity increases*

But findings may:

- *fluctuate*
- *improve*
- *partially normalize*

ABR supports suspicion.

It does not confirm diagnosis alone.

Brainstem Stroke and Degenerative Disorders

In acute lesions:

- *ABR may change dramatically*
- *asymmetry is often stark*

In chronic or degenerative disease:

- *changes are subtle*
- *progression matters more than snapshot*

*Serial ABR can document **trajectory**,
not just presence.*

Central Auditory Disorders: What ABR Can and Cannot Do

ABR:

- *evaluates up to the brainstem*
- *does NOT assess cortical processing*
- *does NOT diagnose CAPD*

Using ABR to label central auditory processing disorder in adults is category error.

*ABR rules out **gross neural dysfunction**.*

Nothing more.

When ABR Is Abnormal but Imaging Is Normal

This is common.

Possible explanations:

- *early neural dysfunction*
- *physiological vulnerability*
- *false-positive ABR interpretation*

Normal imaging does not invalidate ABR.

Abnormal ABR does not mandate pathology.

Correlation—not dominance—guides truth.

Why Adult Neural ABR Is High-Stakes

Adult neural ABR can trigger:

- *MRI referrals*
- *neurology consults*
- *anxiety and fear*

Which means:

every millisecond you interpret must earn its authority.

– Clinical Summary

Adult Neural and Central Auditory Disorders

Key Points

- *Adult neural ABR abnormalities are more stable than pediatric ones.*

- *Interpeak intervals and asymmetry are key indicators.*
- *Rate sensitivity distinguishes neural from conductive pathology.*
- *ABR complements—not replaces—MRI.*
- *Overinterpretation causes real harm.*

Ethics

- *Unnecessary imaging harms trust.*

Documentation

- *Document interpeak analysis clearly.*

Report Writing

- *Avoid alarming language without strong patterns.*
- *Recommend imaging only when criteria are met.*

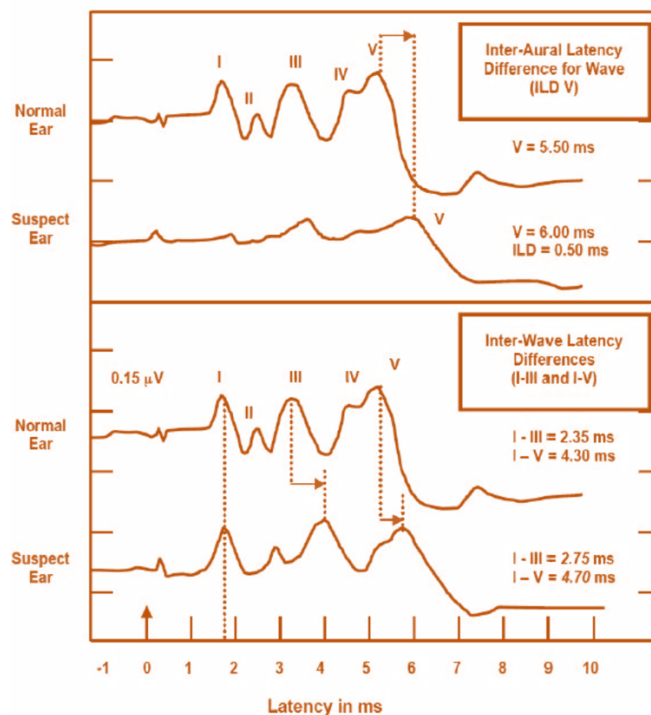


Figure 41.1. Strategies for analysis of ABR in identification of retrocochlear dysfunction including calculation of inter-aural latency difference for absolute wave V latency (top) and for inter-wave latency values (bottom)



CHAPTER

43

Intra-Operative Neurophysiologic Monitoring with ABR

In adults, neural and central

Intra-operative ABR is not audiology.

*It is **neurologic guardianship**.*

There is no time for elegance.

No tolerance for delay.

No room for academic curiosity.

Here, ABR exists for one reason only:

To warn before injury becomes irreversible.

What Makes Intra-Operative ABR Different

This is not diagnostic ABR.

This is not threshold estimation.

*This is **real-time neural surveillance**.*

Key differences:

- *speed over beauty*
- *stability over detail*
- *trends over single measurements*

*If you try to practice routine audiology in the OR,
you will fail the patient.*

Why ABR Is Used Intra-Operatively

ABR monitoring protects:

- *auditory nerve integrity*
- *brainstem pathways*
- *cochlear blood supply*

Used during:

- *vestibular schwannoma surgery*
- *posterior fossa procedures*
- *brainstem and skull base operations*
- *microvascular decompression*

ABR does not guide surgery.

*It **warns when surgery threatens function.***

The Language of Intra-Operative ABR

In the OR, ABR speaks only three sentences:

1. ***Stable***
2. ***Changing***
3. ***Lost***

Anything more is noise.

Latency shifts matter.

Amplitude trends matter.

Waveform beauty does not.

Baseline: The Most Important ABR of the Case

A bad baseline kills monitoring.

Baseline must be:

- *acquired before surgical manipulation*
- *stable and replicable*
- *documented clearly*

A weak baseline means:

- *false alarms*
- *missed injury*
- *loss of trust*

If baseline is poor,

monitoring is compromised—say it clearly.

Take-Home Messages

- *IONM-ABR is about protection, not proof.*

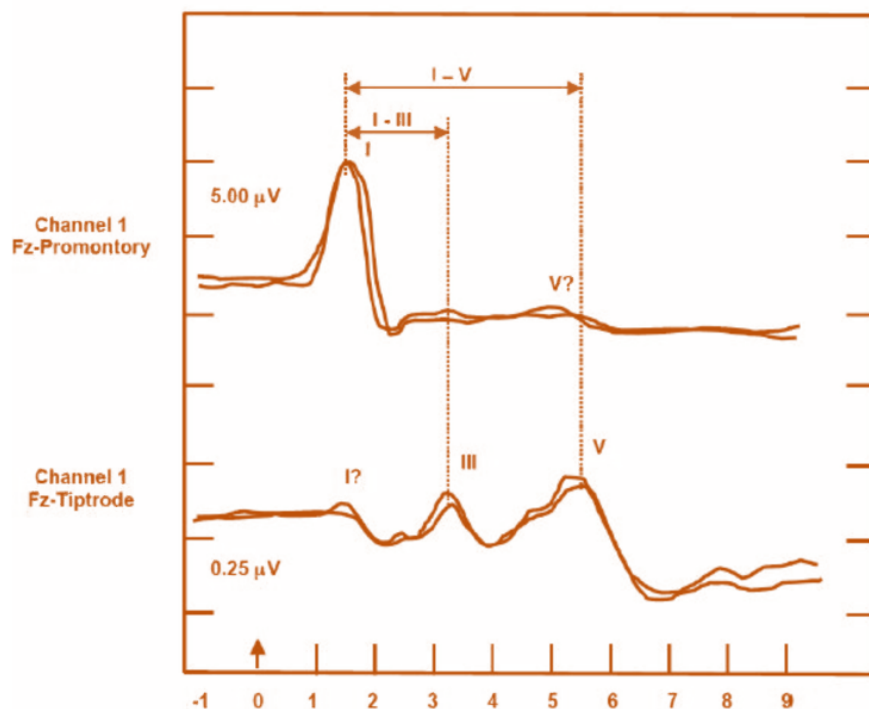


Figure 42.1. Analysis of ABR during intra-operative monitoring with a combined ECoG trans-tympanic promontory electrode



CHAPTER

44

Complex-ABR or cABR

- *Refers to sub-cortical responses evoked by complex sounds of any variet.*
- *Including speech syllables, words , phrases, environmental sounds and music.*

Why Speech??

- *Most speech sounds have a complex harmonic structure.*
- *The auditory brainstem response faithfully preserves the complex harmonic characteristics of speech.*

Speech Stimuli for cABR

cABR stimuli to speech can be created with many different software packages.

- *Natural*
- *Hybrid :some digitization of a natural sounds*
- *Synthetic : Created fully digitally*

Why /da/ ??

- A relatively universal syllable.
- It consists of a transient segment followed by a sustained periodic segment. The transient onset response to the stop burst is similar to the click- ABR, and the sustained response to the vowel is similar to tone-evoked frequency following response (FFR).

Speech acoustic features /da/

The first 10 ms of the syllable are characterized by the onset burst of the consonant /d/; the following 30 ms are the formant transition to the vowel /a/.

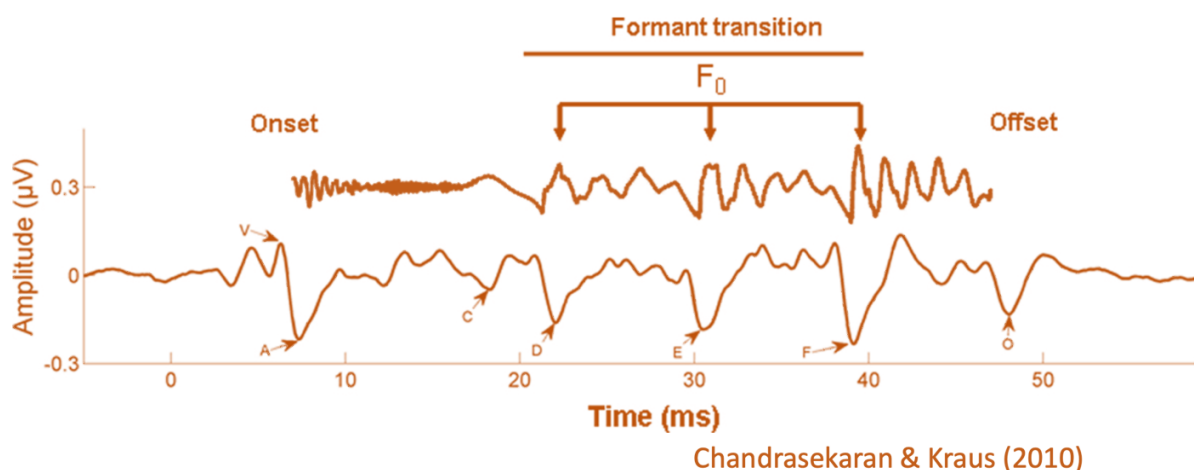


Figure 43.1. Analysis of ABR during intra-operative monitoring with a combined ECoG trans-tympanic promontory electrode.

cABR setup

- Essentially similar to standard ABR
- Same electrode montage
- The averaging window : 100 msec



CHAPTER

45

*ABR Recording in Auditory Neuropathy
Spectrum Disorder(ANSD)*

Auditory Neuropathy Spectrum Disorder

Dys-synchrony or Asynchrony within the auditory nerve

- *Absent or severely abnormal ABR (wave I is always absent)*
- *Absent CAP*
- *Absent Acoustic reflex*

Normal outer hair cell function

- *Intact cochlear microphonics (CM)*
- *Intact OAEs*

ANSD: Diagnostic Criteria

- ☐ *Absent or severely abnormal ABR*
- ☐ *Severely abnormal ABR:*
- ☐ *Absent wave I*
- ☐ *Wave V only at high intensities (above 70 dB nHL)*
- ☐ *Low amplitude and prolonged latency*

- ☐ Absent or elevated AR
- ☐ Intact CM
- ☐ OAEs are present or were at one time present
- ☐ OAEs is absent in 20% -50% of neonates and infants with ANSD

ANSD: Diagnostic Criteria

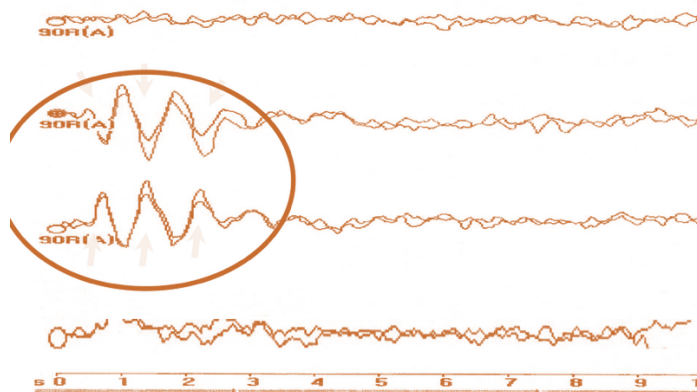
Absent ABR with alternating click polarity

CM with Rarefaction click polarity

CM with Condensation click polarity

Control traces

Insert ear phone must be used to record the CM



The cochlear microphonics

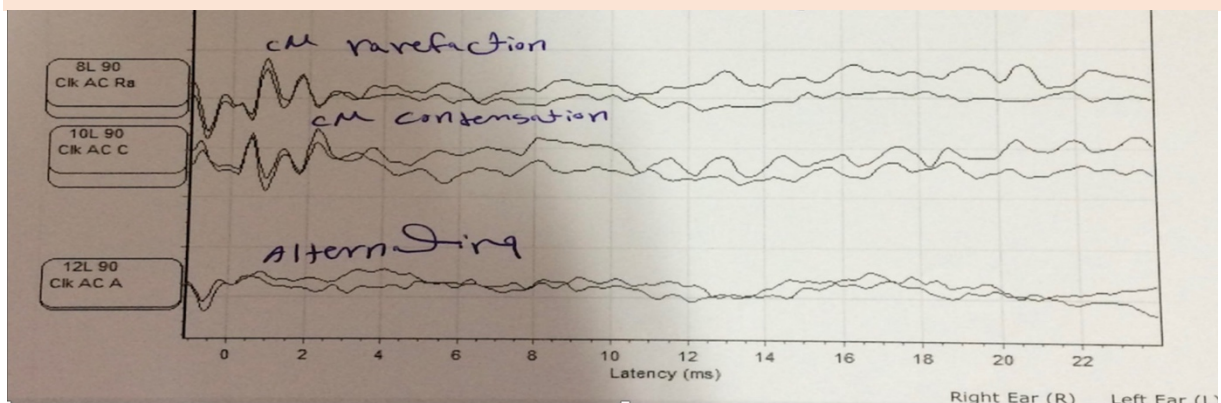


Figure 44.1. ANSD.

ANSD....

A clinical syndrome characterized by electrophysiological evidence of near- normal or normal cochlear function and abnormal auditory pathway

ANSD....

Normal outer hair cell function [present OAEs or a cochlear microphonics (CM)]

Abnormal auditory nerve response [markedly abnormal or absent ABR & absent ARs]

ANSD....

Pure-tone hearing thresholds that range anywhere from normal hearing to profound loss.

Disproportionately poor speech recognition ability

Increased difficulty in noise & impaired temporal processing

Why is it important to diagnose ANSD in infants & children?

- *Incidence: at least 1 in 10 patients with SNHL*
- *Management options differ (HAs – CI – ABI,..)*
- *Counseling issues*

The earlier the diagnosis, the better the management

Therefore, in Neonatal Screening....

Cochlear Microphonic in AN

Larger than normal in patients with AN (Starr et al 2001) possibly due to lack of efferent suppression. Not obliterated by the action potential of the auditory nerve!

Should still be present after OAE disappears and may be the only remaining sign of hair cell function.

How do we measure CM??

- *ECochG*
- *ABR (special protocol)*

What do we expect in ABR??

ABR:

- *Flat with no peaks*
- *Poorly synchronized late peak (? V) at high intensity*

CM:

- *Pre-neural response (occurs before Wave I in the ABR)*
- *CM shows a direct phase relationship to acoustic waveform.*

When polarity of the stimulus is changed there is a reversal of CM waveform

To differentiate CM from Stimulus Artifact

“use insert earphones”

“clamp the tube”

Stimulus Artifact with Headphones

In conclusion:

CM is a receptor potential believed to be generated primarily by OHCs.

Its detection in surface recordings has been considered a distinctive sign of OHC integrity in patients with ANSD

ABR vs. MRI

- ☐ *MRI is more sensitive than ABR in detecting acoustic*

neuroma

- ☐ *ABR may miss small acoustic neuroma (intra-canalicular)*
- ☐ *Effect of hearing loss on ABR*

ABR still has an important role in diagnosis of retro-cochlear lesions

ABR in vestibular schwannoma

- ☐ *Pooled sensitivity for ABR detection of vestibular Schwannomas is 93.4%*
- ☐ *For tumors less than 1cm sensitivity is 85.8%*
- ☐ *For tumors greater than 1cm pooled sensitivity is 95.6%*
- ☐ *Sensitivity of ABR to detect extra-canalicular tumors is higher than for intra-canalicular tumors.*



SECTION

3

Auditory Steady State Response (ASSR)

Auditory Middle Latency Response (AMLR)

Auditory Late Response (ALR)



CHAPTER

46

Auditory Steady State Response (ASSR)

ASSR does not ask,

“Can the brain respond?”

It asks,

“Can the brain follow?”

That difference is everything.

ASSR is not about waveforms.

*It is about **synchrony under continuous demand.***

And that makes it powerful—

and dangerous—at the same time.

It is a sustained AEP elicited with modulated tones.

• The ASSR uses statistical measures (objective) to determine if and when a threshold is present.

What ASSR Really Measures

ASSR measures:

- *the brain’s ability to follow **rapid, repetitive stimulation***
- *frequency-specific neural locking*

- *response strength in the frequency domain*

Unlike ABR:

- *there are no waves to admire*
- *no peaks to label*
- *no latencies to debate*

*ASSR speaks in **statistics**, not shapes.*

Why ASSR Exists

ASSR exists because ABR has limits.

ABR struggles when:

- *hearing loss is severe to profound*
- *responses disappear early*
- *frequency specificity becomes coarse*

ASSR extends estimation:

- *into higher intensities*
- *across multiple frequencies simultaneously*
- *with less reliance on visual judgment*

ASSR was born to answer the question:

“Is there usable hearing left—and where?”

ASSR Is Not “Better ABR”

This is the most common and most misconception.

ASSR:

- *does not replace ABR*
- *does not confirm neural integrity*
- *does not diagnose ANSD*
- *does not assess brainstem timing*

ASSR estimates thresholds.

*ABR assesses **neural function**.*

They serve different masters.

How ASSR Thinks (and Why Clinicians Struggle)

ASSR relies on:

- *phase locking*
- *statistical detection*
- *confidence levels*

Which means:

- *responses can appear “present” without looking convincing*
- *results depend heavily on algorithm assumptions*
- *clinician intuition is limited*

ASSR is less subjective—

but not more truthful.

Frequency Specificity: ASSR’s Greatest Strength

ASSR shines when:

- *multiple frequencies are needed*
- *severe-to-profound loss is suspected*
- *CI candidacy is being explored*

It provides:

- *frequency-specific threshold estimates*
- *often closer to behavioral levels at high intensities*

But frequency specificity does not equal accuracy

*unless **context is respected**.*

ASSR in Severe-to-Profound Hearing Loss

In this range:

- *ABR often disappears*
- *ASSR may still respond*

But:

- *responses near noise floor are fragile*
- *false positives are possible*
- *overconfidence is common*

*ASSR should define **ranges**,
not pretend precision.*

ASSR and ANSD: A Critical Warning

ASSR may show:

- *present responses*
- *seemingly good thresholds*

In ANSD patients.

This does NOT mean:

- *normal neural timing*
- *good speech perception*
- *favorable outcomes*

*ASSR does not assess synchrony quality—
only periodic following.*

*Using ASSR to “rule out” ANSD
is a categorical error.*

ASSR Requires Clinical Supervision—Not Automation

ASSR systems are seductive:

- *automated*

- *fast*
- *confidence percentages*

But automation does not equal safety.

Clinicians must:

- *verify noise conditions*
- *interpret borderline significance carefully*
- *cross-check with ABR, OAE, and history*

ASSR without supervision

creates confident mistakes.

ASSR in Pediatrics vs Adults

In Pediatrics

- *useful in severe loss*
- *supportive—not standalone*
- *must integrate with ABR*

In Adults

- *helpful for non-cooperative patients*
- *CI candidacy support*
- *not a neurodiagnostic tool*

*ASSR changes with population—
just like ABR.*

Why This Chapter Matters

ASSR errors are rarely technical.

*They are **conceptual**.*

Clinicians fail ASSR when they:

- *expect waveforms*

- *trust automation blindly*
- *ignore physiology*

ASSR rewards understanding.

It punishes assumption.

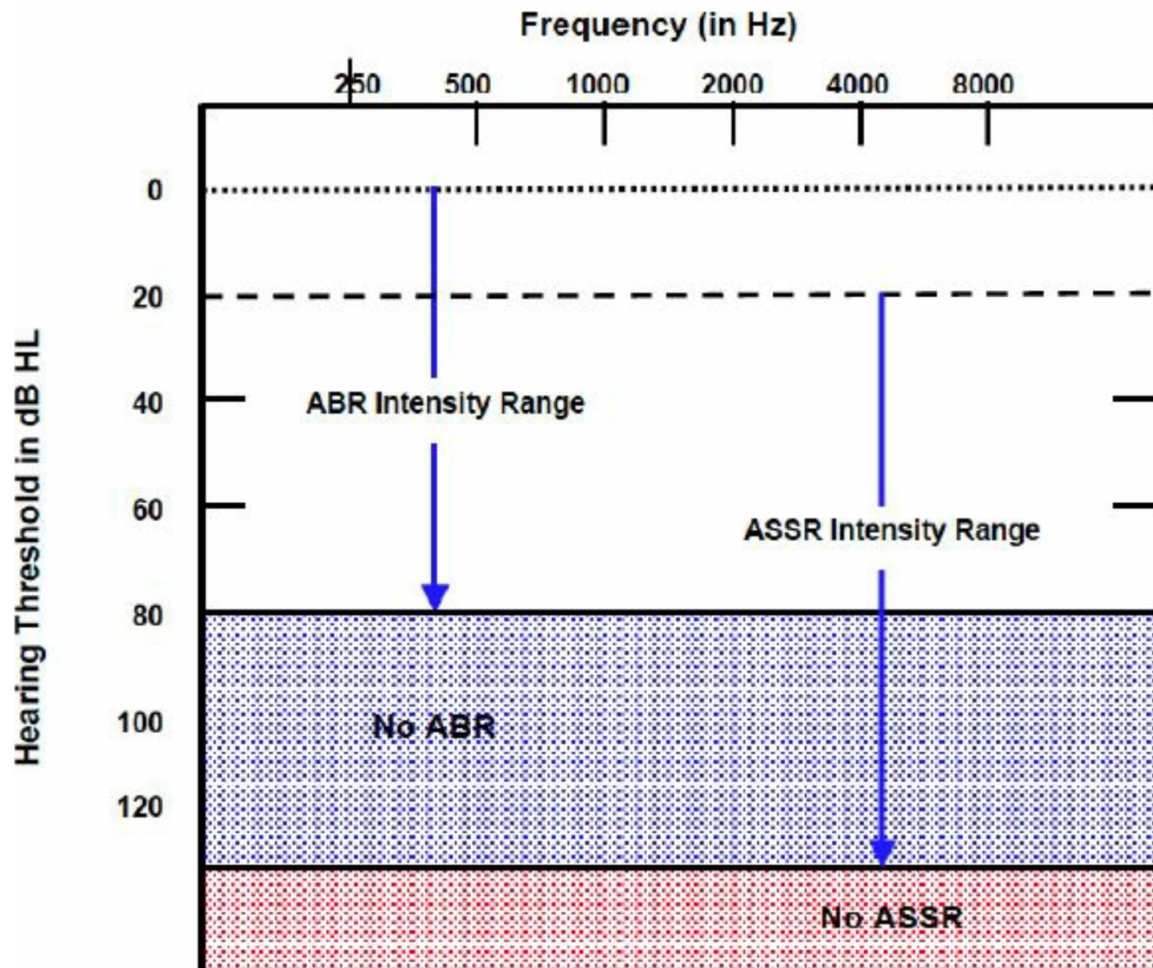
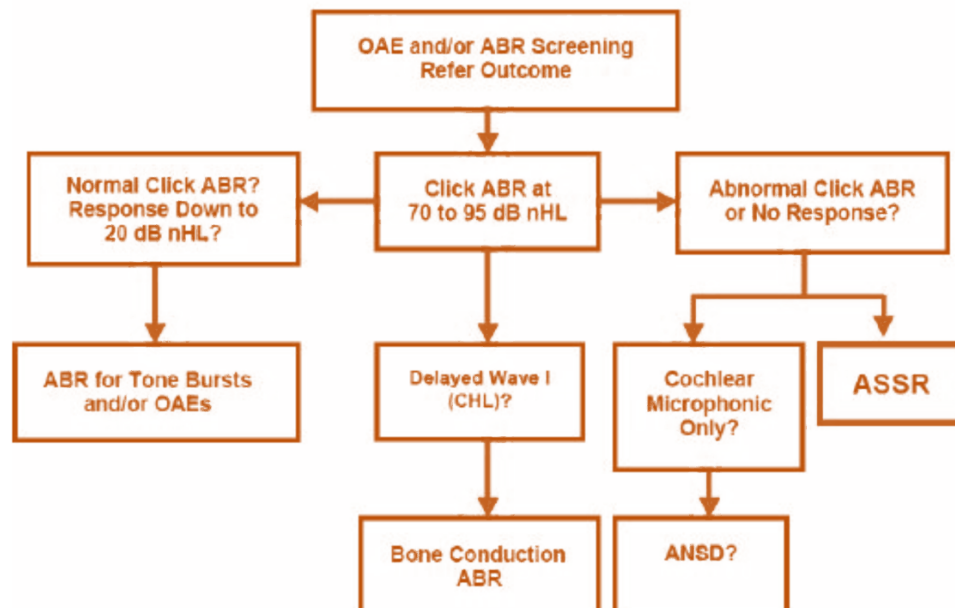


Figure 45.1. Graph illustrating the value of ASSR in estimating auditory thresholds in patients with severe-to-profound hearing loss

- They are generated in response to continuous tone signal or fast rate short duration signals
- ABR is generated in response to **single** stimulus presented at low stimulation rate.

Role of ASSR in Frequency-Specific Estimation of Hearing Thresholds in Infants



Flowchart 45.1. depicting one way ASSR can contribute to hearing assessment in infants and young children.

Indications

I. Assessment of hearing thresholds:

- ***Assessment of hearing thresholds*** objectively in non-cooperate individuals (children, those with cognitive or physical disabilities or inorganic hearing loss).
- The correlation between behavioral thresholds and ASSR was (0.70- 0.93)
- Differences between ASSR and PTA at 2-4 kHz could be as small as 10 dB
- There is a reliable correlation between threshold estimations at low frequencies (0.5 kHz) in young children

II. HA fitting:

- ASSR facilitates HA fittings, especially in very young children as it

give frequency-specific response.

- *Assessment of HAs performance through aided-ASSR since they can be evoked by AM tones, which are frequency-specific and stable over time*

III. Neuro-otological:

- *40-Hz response is reduced in patients with brainstem or thalamic lesions, but not in patients with unilateral lesions of the temporal lobe*
- *Since the 40-Hz response affected by anesthesia, it would be worthwhile to evaluate it in patients with metabolic and toxic encephalopathy*

IV. Non-organic hearing loss:

- *Using the multiple frequency ASSR for behavioral PT threshold estimation in individuals who were in process of claiming compensation of occupational HL*

V. ASSR and auditory neuropathy:

- *In AN patient, the recording rate of ASSR in those patients is higher than ABR*
- *ASSR threshold was higher than the behavioral thresholds specially at 500Hz*

ASSR Compared to ABR

- *Both are AEPs that record bioelectric activity from electrodes arranged in similar recording arrays. ASSR and ABR are both auditory evoked potentials using same electrode montage and delivered through the same transducers*

- **However:**

1. ASSR is evoked using repeated sound stimuli presented at a high repetition rate
2. Detection of response in the spectral (frequency) domain where both the amplitudes and phases are calculated.
3. In ASSR, there is peak detection across a spectrum, rather than peak detection across a time versus amplitude waveform
4. ASSR is not dependent on the examiner subjectively reviewing the waveforms and deciding whether a response is present. ASSR uses an objective, sophisticated, statistics-based mathematical detection algorithm to detect and define hearing thresholds.
5. ASSR can be used binaurally, while evaluating broad bands or four frequencies (500 Hz, 1,000 Hz, 2,000 Hz, and 4,000 Hz) simultaneously
6. ASSR can be used binaurally, while evaluating broad bands or four frequencies (500 Hz, 1,000 Hz, 2,000 Hz, and 4,000 Hz) simultaneously.
7. ASSR can also estimate hearing thresholds across the same range as the TB-ABR, but it offers more spectral information quickly
8. Aided ASSR is more effective in evaluating aided threshold due to the modulated nature of its stimuli.
9. ASSR can estimate and differentiate hearing within the severe-to-profound hearing loss ranges which is very important for CI selection criteria.

ASSR advantages

- ASSR is used as an **objective** test to elicit the response and provide **more specific threshold** information and at **intensity levels of 120 dB**.
- ASSR evoked by tones modulated at frequencies 80-110 Hz can be **obtained from subjects of all ages** regardless of sleep or sedation
- ASSR is **stable over time** and the continuous stimuli are not likely to be distorted in either a sound field speaker or hearing aid amplifier therefore it can be used to assess aided threshold

ASSR limitations

- Its use in the determination of the site of lesion is limited due to uncertainties about the specific regions of brain responsible for generating ASSR.
- It cannot differentiate between hearing losses of peripheral (cochlear origin) and those due to retro-cochlear disorders.
- ASSR is not sufficient as a stand-alone electrophysiological test.

ASSR Setup

- Essentially similar to standard ABR
- Same electrode montage
- Sedation is also needed
- Insert receivers
- Different stimulus

Stimuli for ASSR

Carrier frequency

It is essentially a pure tone which is either modulated in frequency or amplitude:

Frequencies of 500, 1000, 2000 and 4000 Hz are typically used.

How the response is detected ?

- *The ASSR response is very small (nV) and is actually embedded within the EEG noise.*
- *Reliable recording of ASSR depends heavily on achieving best possible signal to noise ratio between the background EEG and ASSR.*
- *Detection of ASSR is done by using computer algorithm which is applied to the recorded EEG signal to analyze the magnitude and the phase of EEG activity corresponding to modulated tone.*
- *Totally objective.*

Construction of an Audiogram

- *Most equipment provides correction tables for converting ASSR thresholds to estimated HL audiograms.*
- *Tables are found to be within 10 dB to 40 dB of audiometric thresholds (depending on the degree of HL and the frequency measured).*
- *Best correlations with audiograms are obtained in the high frequency range 2-4KHz !!*
- *Moderate correlation to mid frequency 0.5-1KHz*
- *Poor correlation with the very low 250Hz*
- *Accordingly, ASSR is closer to tonal ABR*

Audiogram estimation

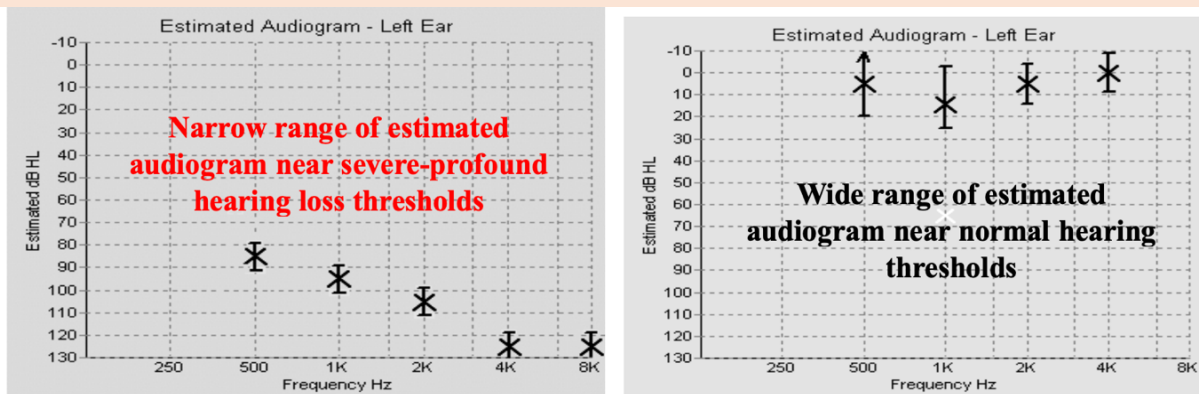


Figure 45.2. Graph illustrating the value of ASSR in estimating auditory thresholds in patients with severe-to-profound hearing loss.

Common Mistakes

- *Using ASSR as a neurodiagnostic test*
- *Ignoring ANSD implications.*



CHAPTER

47

Auditory Middle Latency Response (AMLR)

“Can the brain respond?”

It asks,

“Can the brain follow?”

If ABR asks,

“Is the pathway intact?”

AMLR asks the more question:

“Is the system actually engaging?”

*AMLR lives where certainty weakens
and interpretation demands restraint.*

It is not popular.

It is not easy.

And that is exactly why it matters.

What AMLR Really Is

AMLR reflects neural activity from:

- *thalamocortical pathways*
- *primary auditory cortex vicinity*

- *early cortical engagement*

Time window:

- *approximately **10–50 ms** post-stimulus*

Key components:

- *Na*
- *Pa*
- *Nb*

These are not waves to admire.

*They are **signatures of cortical access**.*

Why AMLR Exists

ABR stops at the brainstem.

Cortical potentials come later.

AMLR exists to answer:

Is auditory information reaching and engaging higher auditory centers?

It bridges:

- *physiology and perception*
- *integrity and awareness*

But bridges are fragile.

And AMLR breaks easily under poor discipline.

Why AMLR Is Clinically Difficult

AMLR is:

- *highly sensitive to state*
- *easily contaminated by muscle artifact*
- *influenced by attention and arousal*

Which means:

- *sleep may abolish it*
- *sedation may distort it*
- *tension may fake it*

*AMLR punishes sloppy setup
more than any other evoked potential.*

AMLR Is Not a Screening Tool

This cannot be overstated.

AMLR:

- *does NOT screen hearing*
- *does NOT estimate thresholds reliably*
- *does NOT replace ABR or ASSR*

*Using AMLR as a primary test
is misunderstanding its purpose.*

*AMLR is **confirmatory and contextual**.*

Clinical Indications for AMLR

AMLR may be useful when:

- *ABR is normal but complaints persist*
- *central auditory involvement is suspected*
- *functional auditory engagement is questioned*
- *medico-legal or research contexts exist*

*But AMLR must **never stand alone**.*

It supports hypotheses.

It does not generate diagnoses.

AMLR in Central Auditory Disorders

AMLR abnormalities may suggest:

- *thalamocortical dysfunction*
- *impaired cortical engagement*
- *delayed central processing*

But:

- *absence is common in normal individuals*
- *presence does not guarantee function*

AMLR does not diagnose CAPD.

*It only **supports or weakens suspicion.***

The State Problem: AMLR's Achilles Heel

AMLR requires:

- *quiet wakefulness*
- *minimal muscle tension*
- *stable alertness*

Which makes it:

- *unreliable in infants*
- *challenging in anxious adults*
- *fragile under sedation*

If patient state is poor,

do not interpret—document limitation and stop.

AMLR is not “better.”

*It is **different—and narrower.***

Why AMLR Is Often Misused

Because clinicians want:

- *something “beyond ABR”*

- *objective proof of listening*
- *confirmation of complaints*

AMLR cannot carry that weight alone.

*When forced to answer questions it was never built for,
AMLR lies politely.*

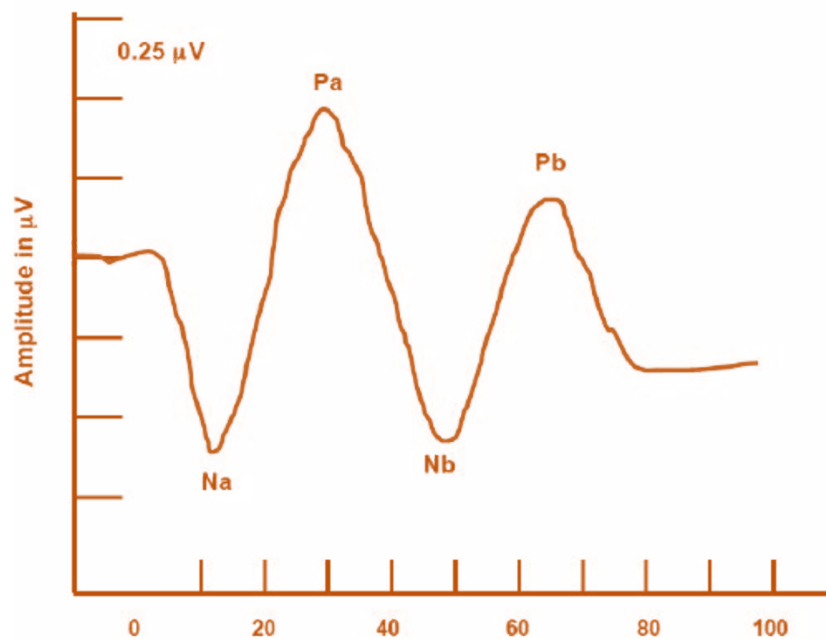


Figure 46.1. AMLR waveform showing major peaks at typical latencies including Na, Pa, Nb, and Pb

Common Mistakes

- *Using AMLR as a diagnostic endpoint.*
- *Interpreting absent AMLR as pathology.*
- *Ignoring patient state and muscle artifact.*
- *Using AMLR to diagnose CAPD.*



CHAPTER

48

Auditory Late Response (ALR)
Clinical Applications – P300 & MMN



If ABR asks “Did the signal arrive?”

and AMLR asks “Did the cortex engage?”

ALR asks the most question of all:

“Did the brain understand?”

This is no longer audiology in the narrow sense.

*This is **auditory cognition**.*

And that is why ALR must be handled

*with the **highest intellectual restraint**.*

What ALR Really Represents

ALR reflects:

- *cortical auditory processing*
- *attention and discrimination*
- *auditory memory and expectation*

Time window:

- ~ **50–300+ ms**

Key components:

- **P1 – N1 – P2**
- **N2 – P300**
- **MMN**

These are not hearing responses.

They are **listening responses**.

Why ALR Exists

ALR exists because:

- normal thresholds do not guarantee understanding
- intact brainstem does not ensure perception
- hearing devices do not equal listening success

ALR answers questions audiometry cannot:

- Is sound being detected meaningfully?
- Is attention recruited?
- Is change recognized automatically?

But ALR **never works alone**.

Clinical Applications of ALR

ALR is useful when:

- patients report listening difficulty with normal audiograms
- outcomes after hearing aid or CI fitting are unclear
- cognitive-auditory interaction is suspected
- research or medico-legal questions arise

ALR is **functional evidence**, not diagnostic proof.

P300: The Attention-Dependent Response

What P300 Measures

P300 reflects:

- *conscious discrimination*
- *attention allocation*
- *auditory working memory*

It requires:

- *active participation*
- *task understanding*
- *stable cognitive state*

Which means:

- *P300 $\neq$ hearing*
- *P300 $\neq$ intelligence*
- *P300 $\neq$ motivation*

*It measures **engaged discrimination under task demands.***

Clinical Meaning of P300

- *Prolonged latency $\rightarrow$ slowed cognitive processing*
- *Reduced amplitude $\rightarrow$ reduced attentional resources*

But:

- *age affects P300 strongly*
- *fatigue alters results*
- *anxiety distorts outcomes*

P300 does not diagnose disease.

*It **describes processing under conditions.***

Mismatch Negativity (MMN): The Automatic Brain

MMN answers a different question:

“Does the brain detect change—even when the person is not paying attention?”

MMN reflects:

- *pre-attentive discrimination*
- *sensory memory integrity*
- *automatic cortical processing*

*MMN does **not** require:*

- *cooperation*
- *attention*
- *behavioral response*

Which makes it powerful—and dangerous.

Clinical Use of MMN

MMN may be useful in:

- *infants and young children*
- *uncooperative patients*
- *cognitive impairment*
- *outcome monitoring*

But:

- *MMN presence $\neq$ normal perception*
- *MMN absence $\neq$ dysfunction*

*MMN reflects **change detection**, not understanding.*

ALR, P300, MMN: What They Do NOT Do

They do NOT:

- *diagnose CAPD alone*
- *replace behavioral assessment*

- *predict real-world communication*
- *confirm benefit from devices conclusively*

*These responses describe **brain behavior**, not life performance.*

The State & Cognitive Problem

ALR is extremely sensitive to:

- *attention*
- *fatigue*
- *motivation*
- *cognitive load*

Which means:

- *poor cooperation = meaningless data*
- *sedation invalidates interpretation*
- *overinterpretation is common*

If cognitive state is not controlled,

stop interpreting.

Why ALR Is the Most Abused Evoked Potential

Because clinicians want:

- *objective proof of listening*
- *validation of complaints*
- *confirmation of outcomes*

ALR cannot carry emotional expectations.

When forced, it lies quietly.

Key Points

- *ALR reflects cortical auditory processing.*

- *P300 is attention-dependent.*
- *MMN is pre-attentive and automatic.*
- *These are listening—not hearing—responses.*
- *Interpretation requires cognitive context.*

Common Mistakes

- *Diagnosing CAPD from ALR alone.*
- *Ignoring attention and fatigue.*
- *Treating absence as pathology.*



SECTION

4

(eABR)

(P1 Test)

(Aided ABR)

Evidence-based reporting

CHAPTER

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*Electric Auditory Brainstem Response (eABR)
in Cochlear Implant Users*



If ABR asks “Did the signal arrive?”

and AMLR asks “Did the cortex engage?”

ALR asks the most question of all:

Electric ABR is not hearing.

*It is **neural accountability**.*

When sound is replaced by electricity,

ABR becomes the only witness

that the auditory nerve is still listening.

Not to sound.

*But to **intention**.*

What Electric ABR Really Is

Electric ABR (eABR):

- *records brainstem responses*
- *evoked by **direct electrical stimulation***
- *delivered through CI electrodes*

No middle ear.

No cochlea.

No acoustic mechanics.

Only:

- *electrode*
- *nerve*
- *brainstem*

*This makes eABR **pure neural physiology**.*

And that is why it is to misuse.

Why eABR Exists

eABR exists to answer questions that no other test can:

- *Is the auditory nerve excitable?*
- *Does electrical stimulation reach the brainstem?*
- *Is neural conduction preserved beyond the cochlea?*

eABR is used when:

- *acoustic ABR is absent or uninterpretable*
- *cochlear implantation is planned or ongoing*
- *intra-operative or post-operative confirmation is needed*

eABR does not predict speech.

*It confirms **pathway viability**.*

When eABR Is Clinically Indicated

eABR may be used in:

- *CI candidacy evaluation (selected cases)*
- *intra-operative CI monitoring*
- *post-operative neural integrity confirmation*

- *cases of suspected cochlear nerve deficiency*
- *complex malformations*

*It is **not routine**.*

*It is **targeted**.*

Waveform Characteristics in eABR

Typical features:

- *identifiable Wave III and V equivalents*
- *shorter absolute latencies*
- *reduced inter-individual variability*

Wave I is often:

- *absent*
- *unreliable*
- *not expected*

Absence of Wave I in eABR

is not pathology.

eABR in Cochlear Nerve Deficiency (CND)

This is where eABR becomes decisive.

- *Absent acoustic ABR*
- *Absent OAEs*
- *Unclear MRI findings*

eABR may:

- *demonstrate neural excitability*
- *support CI trial*
- *guide family counseling*

But:

- *presence ≠ good outcome*
- *absence ≠ absolute contraindication*

*eABR informs **risk**, not destiny.*

Intra-Operative eABR

During CI surgery, eABR may:

- *confirm electrode function*
- *verify neural activation*
- *detect gross electrode issues*

Intra-op eABR:

- *is trend-based*
- *is confirmation—not optimization*
- *does not replace telemetry*

It answers only one question:

Is the nerve responding right now?

eABR vs ECAP (NRT / ART / NRI).

What eABR Does NOT Do

eABR does NOT:

- *estimate hearing thresholds*
- *predict speech perception*
- *replace behavioral mapping*
- *determine CI success*

Any report implying that

is scientifically irresponsible.

Common Mistakes

- *Using eABR to predict speech outcomes.*

- *Comparing electric latencies to acoustic norms.*
- *Treating eABR as a threshold test.*

Red Flags

- *CI decisions based solely on eABR.*
- *Definitive language about outcomes.*
- *Ignoring complementary measures (ECAP, imaging).*

Ethics

- *eABR presence does not guarantee benefit.*
- *Honest counseling protects families.*
- *Overpromise harms trust.*



CHAPTER

50

P1 Cortical Auditory Evoked Potential (P1 Test)

If ABR asks “Is the pathway intact?”

and ASSR asks “Is there measurable sensitivity?”

P1 asks the only question that matters after intervention:

“Did sound reach the developing auditory cortex in time?”

P1 is not diagnosis.

*It is **developmental accountability**.*

What the P1 Test Really Is

P1 is:

- *an **early cortical auditory evoked potential***
- *generated from auditory cortex activation*
- *strongly dependent on **auditory experience***

Time window:

- *approximately **50–150 ms** (age-dependent)*

P1 is not about hearing levels.

*It is about **cortical maturation driven by sound**.*

Why P1 Exists

Children can:

- *wear hearing aids*
- *receive cochlear implants*
- *pass objective tests*

And still:

- *not develop normal auditory cortex*

P1 exists to answer:

Is the brain receiving enough meaningful sound early enough to mature normally?

No other test answers this.

The Critical Concept: Sensitive Period

Auditory cortex development is time-bound.

- *Early sound → normal P1 latency*
- *Delayed sound → delayed or abnormal P1*
- *No sound → absent or severely delayed P1*

*P1 is a **biological clock**,*

not a hearing test.

Miss the window,

and no technology can fully compensate.

Normal vs Abnormal P1: What Matters

Normal P1

- *Age-appropriate latency*
- *Clear, replicable waveform*

Abnormal P1

- *Prolonged latency*

- *Poor morphology*
- *Absence*

But:

- *absence $\neq$ hopeless*
- *presence $\neq$ success*

Trajectory matters more than snapshot.

P1 in Hearing Aid Users

P1 can:

- *confirm cortical access to amplified sound*
- *monitor maturation over time*
- *reveal under-amplification*

If P1 latency does not improve:

- *fitting may be inadequate*
- *access may be insufficient*

P1 turns fitting from guesswork

*into **neurodevelopmental monitoring**.*

P1 in Cochlear Implant Users

This is where P1 becomes decisive.

- *Early implantation $\rightarrow$ rapid P1 normalization*
- *Late implantation $\rightarrow$ delayed or abnormal P1*

P1 does not measure speech.

*It measures **whether the brain had a chance**.*

CI success without cortical access

is accidental—not reliable.

P1 vs Behavioral Outcomes

P1:

- *predicts potential*
- *does not predict performance*

Children may:

- *show normal P1 and still struggle*
- *show delayed P1 and later improve*

*P1 is a **necessary condition**,*

not a sufficient one.

Recording P1: Why Discipline Matters

P1 requires:

- *quiet wakefulness or light sleep*
- *minimal movement*
- *appropriate stimulus*
- *age-matched norms*

Sedation:

- *distorts interpretation*
- *removes developmental meaning*

If state is wrong,

do not interpret P1.

What P1 Does NOT Do

P1 does NOT:

- *diagnose hearing loss*
- *replace ABR or ASSR*
- *guarantee language outcomes*
- *justify delayed intervention*

P1 answers one question only:

Is the cortex being stimulated in time?

Because many children:

- *“pass” objective tests*
- *wear devices*
- *still fail to develop listening*

P1 explains why.

Key Points

- *P1 reflects auditory cortical maturation.*
- *Strongly dependent on early auditory experience.*
- *Sensitive to timing of intervention.*
- *Useful in HA and CI outcome monitoring.*
- *Interpretation must be developmental.*

Common Mistakes

- *Using P1 as a diagnostic test.*
- *Interpreting absence as failure.*
- *Ignoring age-related norms.*
- *Testing under inappropriate state.*

Red Flags

- *Persistent delayed P1 despite amplification.*
- *No improvement over time.*

Best-Practice Principles

- *Use P1 to monitor cortical access after intervention.*



CHAPTER

51

eABR vs ECAP: Clinical Decision Algorithms

If ECAP asks:

“Did the nerve fire?”

eABR asks:

“Did the brainstem receive the message?”

And confusing the two

is one of the most expensive mistakes in CI practice.

Decision Algorithm (Real Life)

Scenario 1: Normal ECAP + Normal eABR

Right Neural activation

Right Brainstem transmission

Low-risk neural pathway

CI decision supported (not guaranteed)

Scenario 2: ECAP Present + eABR Absent

Right Nerve fires

Wrong Central transmission questionable

High-risk CI

Counsel cautiously

Consider imaging, plasticity limits

Scenario 3: ECAP Absent + eABR Present

Rare — suspect:

- *recording artifact*
- *electrode issues*

Re-evaluate setup before decisions

Scenario 4: Both Absent

Wrong Nerve activation

Wrong Brainstem response

CI benefit questionable

ABI discussion may be appropriate



CHAPTER

52

*Aided Auditory Brainstem Response (Aided ABR)**When Sound Is Amplified, What Exactly Are We Measuring?*

Aided ABR looks simple.

*In reality, it is one of the **most misunderstood procedures in audiology**.*

*Because the moment amplification enters the equation, **physiology, technology, and interpretation collide**.*

*This chapter exists to put Aided ABR back in its **correct clinical position**.*

What Aided ABR Really Is

Aided ABR is:

- *brainstem response*
- *evoked by **amplified acoustic input***
- *delivered through a hearing aid or sound processor*

*It does **not** measure:*

- *hearing aid quality*
- *speech understanding*

- *fitting accuracy in isolation*

*It measures **neural detection of amplified sound** under very specific conditions.*

Why Aided ABR Exists

*Aided ABR exists to answer **one question only**:*

Is amplified sound reaching the auditory brainstem at detectable levels?

*It does **not** answer:*

- *Is amplification optimal?*
- *Is speech audible?*
- *Will the patient benefit functionally?*

Those are different questions—and different tools.

Clinical Indications for Aided ABR

Aided ABR may be useful in:

- *infants or young children unable to perform behavioral testing*
- *suspected severe–profound hearing loss*
- *verification of **audibility**, not performance*
- *selected medico-legal or documentation contexts*

*It is **not a routine fitting tool**.*

Aided ABR does not replace REM.

*It answers a **different physiological question**.*

Stimulus Considerations in Aided ABR

Stimulus Type

- *Click ABR → broadband detection only*
- *Tone-burst ABR → frequency-specific access (preferred)*

Speech Stimuli

- *Attractive*
- *Clinically if overinterpreted*

A brainstem response to speech ≠ speech understanding.

Hearing Aid Variables That Affect Aided ABR

This is where errors multiply.

Aided ABR is influenced by:

- *compression*
- *attack/release times*
- *noise reduction*
- *frequency shaping*
- *maximum output limits*

Which means:

You are not testing “the ear” alone—you are testing the algorithm.

Why Aided ABR Often Misleads

Because:

- *presence of response feels reassuring*
- *absence feels diagnostic*

But:

- *response may reflect low-frequency energy only*
- *absence may reflect aggressive noise reduction*
- *latency shifts may reflect processing delay—not neural pathology*

When Aided ABR Should NOT Be Used

- *As a substitute for REM*

- *As proof of “good hearing aid fitting”*
- *As outcome prediction*
- *In isolation without documentation of HA settings*

Key Points

- *Aided ABR measures neural detection of amplified sound.*

Common Mistakes

- *Treating absence as fitting failure.*
- *Replacing REM with Aided ABR.*



CHAPTER

53

Evidence-based reporting

*Evidence-based reporting gives us **one clear language** everyone understands.*

*This chapter is written for those who face one of the biggest challenges in audiology training: **writing clear, professional, and clinically useful reports.***

I will take you step by step—

*From the basics of **evidence-based writing***

*Through **adult and pediatric reports***

*All the way to **advanced and special cases***

The purpose of this chapter:

*To help you **master the art of writing clear, concise, and evidence-based audiology reports.***

*Report writing is not just paperwork—it's a reflection of your **clinical reasoning.** A well-structured report can:*

Guide medical decisions

Support rehabilitation plans

Build trust with patients and colleagues

*Unfortunately, many students find report writing either **too complicated or too dry**. This manual aims to change that.*

Here, you'll find:

Simple, practical guidance

Evidence-based principles

Ready-to-use templates

***Training-style explanations** that are easy to follow and remember*

*By the end of this book, my hope is that you will not only write reports—you will **communicate effectively**, **add value to patient care**, **and gain confidence as a future audiologist**.*

Auditory Brainstem Response (ABR) – Clicks & CE-Chirp®

ABR is an **objective electrophysiological test** that measures neural synchrony from the auditory nerve to the brainstem.

- **Clicks**: broad-spectrum (2–4 kHz region).
- **CE-Chirp®**: enhances synchrony → clearer waves, lower thresholds.
- Sedation may be needed in infants/children.
- Wave V is the **most robust** marker for threshold estimation.
- Thresholds are **estimates**, not exact behavioral HL.

Tone Burst ABR (Frequency-Specific Thresholds)

Tone Burst ABR gives **frequency-specific thresholds** (500, 1000, 2000, 4000 Hz).

Used for more accurate **audiogram prediction**.

- rate (37.7/s).
- Alternating polarity preferred (reduces artifact).
- Cross-check with behavioral audiometry when possible.



Example Report

Result: Bilateral ABR waves detected at 90 dBnHL. Wave V traced down to 30 dBnHL in both ears.

Interpretation: Normal neural synchrony, thresholds within normal limits (2–4 kHz).

Recommendation: Follow with age-appropriate behavioral audiometry.

Tips & Pitfalls

Always check **impedance** ($< 5 \text{ k}\Omega$) before starting.

Note **test condition** (natural sleep vs anesthesia).

Don't over-interpret – ABR = estimate, not exact audiogram.

Example Report

Result:

- RT: 500 Hz = 30 dBnHL, 1000 Hz = 25, 2000 Hz = 25, 4000 Hz = 30
- LT: 500 Hz = 30, 1000 Hz = 30, 2000 Hz = 25, 4000 Hz = 30

Interpretation: Normal to near-normal thresholds across frequencies.

Tips & Pitfalls

Tone Burst = better frequency specificity than clicks.

Low frequencies (500 Hz) may be harder to record → check multiple runs.

Don't forget to label **“estimated” thresholds** in the report.



Auditory Brainstem Response (ABR) Neural Synchrony (clicks & CE-Chirp®)

File NO:

Date:

Name: Sex: Age:

Reason for Referral: ☐ Failed newborn screening ☐ Speech delay ☐ Family history of hearing loss ☐ Follow-up ☐ Other: _____Sedation: ☐ None – Natural Sleep ☐ General AnesthesiaTest Environment: ☐ Sound-treated booth ☐ Quiet hospital room ☐ Operating room

Stimulus Type & polarity: Rarefaction acoustic clicks and (CE-Chirp®) stimuli (to enhance neural synchrony across frequency regions) were presented monaurally at rate of 27.5 p/sec., and intensity of 90 dBnHL down to threshold in 10-20 dB steps.

Equipment: Vivosonic Integrity™ ABR system**Transducer:** Vivosonic Integrity™. Insert Earphones (ER-3C)**Electrode Montage:** Non-inverting (Active): High forehead (Fz).• **Inverting:** Mastoid / Earlobe.• **Ground:** Low forehead.**Number of Sweeps:** _____ (2000–4000)**Filter:** 30–1500 Hz (infants)**Impedance Check:** All electrodes $\leq 5 \text{ k}\Omega$.Inter-electrode difference $\leq 2 \text{ k}\Omega$ **Result:** Bilateral **identifiable and repeatable ABR** waves could be detected at 90 dBnHL,

Wave (V) could be traced down to 30 dBnHL in both ears.

Diagnosis and conclusion:

ABR results indicate **Bilateral normal neural synchrony**, normal auditory brainstem pathway function, and **hearing sensitivity within normal levels**, with thresholds estimated to be within the 2–4 kHz frequency region.

Recommendations:

* **Age-appropriate behavioral audiometry** ☐ Visual Reinforcement Audiometry ☐ Conditioned Play Audiometry ☐ Behavioral Observation Audiometry).

* **Acoustic immittance testing** – to evaluate middle ear function..* **Monitor Speech & Language Development.**

* **Audiologic follow-up** is recommended, **including frequency-specific Tone Burst ABR with Narrow-Band CE-Chirp® stimuli**, for a more comprehensive evaluation of auditory function.



Auditory Brainstem Response (ABR) Threshold Determination Report – Tone Burst Narrow- Band CE-Chirp®

◆ Stimulus Parameters – Tone Burst ABR

- **Stimulus Type:** Tone Burst (Frequency-specific)
- **Frequencies Tested:**
 - ☐ 500 Hz
 - ☐ 1000 Hz
 - ☐ 2000 Hz
 - ☐ 4000 Hz
- **Polarity:** Alternating.
- **Presentation Rate:** 37.7 stimuli/second.
- **Filter Settings:** 30 – 1500 Hz
- **Averaging:** 2000–4000 sweeps
- **Intensity Levels:** From 90 dBnHL descending in 10 or 20 dB steps

◆ Results – Tone Burst ABR

Wave V Threshold Estimation

Frequency	Right Ear Threshold	Left Ear Threshold
500 Hz	_____ dBnHL	_____ dBnHL
1000 Hz	_____ dBnHL	_____ dBnHL
2000 Hz	_____ dBnHL	_____ dBnHL
4000 Hz	_____ dBnHL	_____ dBnHL

Correction Factors:

- ABR thresholds are documented in dBeHL values.

• Correction Factors:

	500 Hz	1kHz	Click	2kHz	4kHz
Air Conduction	-20dB	-15dB	-10dB	-10dB	-10dB
Bone Conduction			-20dB		



Notes :



Auditory brainstem response (ABR) Threshold Determination

File NO:

Date:

Name: Sex: Age:

Reason for Referral: ☐ Failed newborn screening ☐ Speech delay ☐ Family history of hearing loss ☐ Follow-up ☐ Other: _____

Sedation: ☐ None – Natural Sleep ☐ General Anesthesia

Test Environment: ☐ Sound-treated booth ☐ Quiet hospital room ☐ Operating room

Stimulus Type & polarity: Rarefaction acoustic clicks were presented monaurally at rate of 27.5 p/sec., and intensity of 90 dBnHL down to threshold in 10-20 dB steps.

Equipment : Vivosonic Integrity™.

Transducer : Vivosonic Integrity™. Insert Earphones (ER-3C)

Electrode Montage: Non-inverting (Active): High forehead (Fz)

• Inverting: Mastoid / Earlobe forehead

• Ground: Low

Number of Sweeps: _____ (2000–4000)

Filter settings: 30–1,500 Hz (infant)

Impedance Check: All electrodes $\leq 5 \text{ k}\Omega$.
difference $\leq 2 \text{ k}\Omega$

Inter-electrode

Result:

No identifiable or repeatable ABR waves (**Wave V absent**) at maximum stimulus (**90 dBnHL**) bilaterally.

Diagnosis and conclusion:

Bilateral **severe to profound** hearing loss at least at frequency region 2-4 KHZ



Tone Burst ABR & Narrow-Band CE-Chirp® stimuli, for more comprehensive evaluation of auditory function.

Auditory Brainstem Response (ABR) Threshold Determination Report – Tone Burst Narrow-Band CE-Chirp®

◆ ***Stimulus Parameters – Tone Burst ABR***

- **Stimulus Type:** Tone Burst (Frequency-specific)
- **Frequencies Tested:**
 - ☐ 500 Hz
 - ☐ 1000 Hz
 - ☐ 2000 Hz
 - ☐ 4000 Hz
- **Polarity:** Alternating.
- **Presentation Rate:** 37.7 stimuli/second.
- **Filter Settings:** 30 – 1500 Hz
- **Averaging:** 2000–4000 sweeps
- **Intensity Levels:** From 90 dBnHL descending in 10 or 20 dB steps

◆ ***Results – Tone Burst ABR***

Wave V Threshold Estimation

<i>Frequency</i>	<i>Right Ear Threshold</i>	<i>Left Ear Threshold</i>
500 Hz	_____ dBnHL	_____ dBnHL
1000 Hz	_____ dBnHL	_____ dBnHL
2000 Hz	_____ dBnHL	_____ dBnHL
4000 Hz	_____ dBnHL	_____ dBnHL

Correction Factors:

- ABR thresholds are documented in dBnHL values.

• Correction Factors:

	500 Hz	1kHz	Click	2kHz	4kHz
Air Conduction	-20dB	-15dB	-10dB	-10dB	-10dB
Bone Conduction			-20dB		



Notes _____

Recommendations:

- * ***Otoacoustic Emissions (OAEs) Testing*** – for further assess cochlear (outer hair cell) function.
- * ***Behavioral audiometry*** test.
- * ***ENT (Otolaryngology) Consultation*** – for further evaluation, counseling, and consideration of imaging studies (e.g., MRI/CT).
- * ***Phoniatric Consultation & Speech Therapy*** – to support speech and language development.
- * ***Binaural Hearing Aid Fitting*** –to support auditory access.
- * ***Consideration for Cochlear Implantation*** – if limited or no benefit from hearing aids, especially given the severity of the hearing loss and absent ABR response.
- * ***Regular Audiological Follow-Up*** – to monitor hearing levels, hearing aid performance, and progress.

****For more relevant details: Kindly refer to the attached ABR waveforms***



Auditory Neuropathy Spectrum Disorder (ANSD) & Cochlear Microphonic (CM)

ANSD = normal OHC function but abnormal neural synchrony.

- *OAE / CM present*
- *ABR absent or grossly abnormal*

Key Points

- *Use **rarefaction & condensation** clicks → polarity reversal confirms CM.*
- *Alternating polarity → cancels CM (rules out artifact).*
- *ANSD suspected when **CM present but no ABR waves***

Example Report

Result: CM robust bilaterally with polarity reversal. ABR absent up to 90 dBnHL.

Interpretation: Findings consistent with ***Auditory Neuropathy Spectrum Disorder.***

Recommendation:

- *OAE to confirm OHC integrity.*
- *Trial with hearing aids ± consider CI if limited benefit.*
- *Speech-language therapy.*

Tips & Pitfalls

*Always verify CM by **clamping insert** (exclude artifact).*

*Don't confuse **absent ABR** with profound SNHL → check CM/OAE first.*

ANSD = management challenge → multidisciplinary care (ENT + Speech therapy).

Cochlear Microphonic (CM) Protocol

File NO:

Date:

Name:Sex:

.....Age:

Reason for Referral: ☐ Failed newborn screening ☐ Speech delay ☐
 Family history of hearing loss ☐ Follow-up ☐ Other: _____

Sedation: ☐ None – Natural Sleep ☐ General
 Anesthesia

Test Environment: ☐ Sound-treated booth ☐ Quiet hospital room
☐ Operating room

Stimulus Type & polarity: **Cochlear Microphonic (CM) Protocol**
 Rarefaction, condensation, and alternating clicks with, 27.5 p/sec,
 90 dBnHL

To differentiate neural vs. hair-cell responses.

Transducer verification: Insert earphones were acoustically blocked
 (clamped) during part of CM recording using Rarefaction or
 Condensation polarity to rule out stimulus artifact.

Equipment : Vivosonic Integrity™ ABR system

Trasducer : Vivosonic Integrity™. Insert Earphones (ER-3C)

Electrode Montage: Non-inverting (Active): High forehead (Fz).

• Inverting: Mastoid / Earlobe. •

Ground: Low forehead.

Number of Sweeps: _____ (2000–4000)

Filter : 30–1500 Hz (infants)

Impedance Check: All electrodes $\leq 5 \text{ k}\Omega$. Inter-
 electrode difference $\leq 2 \text{ k}\Omega$

Result: No identifiable or repeatable ABR waves (**Wave V absent**) at
 maximum stimulus (**90 dBnHL**) bilaterally.

Cochlear Microphonic

***Rarefaction & Condensation:** Robust **CM** detected bilaterally;
 polarity reversal confirms hair-cell origin .

***Alternating** polarity: **CM abolished**, indicating true cochlear
 microphonic presence rather than stimulus artifact.

*CM disappeared when insert is **clamped**.*

Diagnosis and conclusion:

*Findings are highly suggestive of bilateral auditory neuropathy spectrum disorder (**ANSD**): absent neural synchronization on ABR with preserved **cochlear microphonics**.*

Recommendations:

* **Otoacoustic Emissions (OAEs) Testing** – to confirm outer hair cell function and support ANSD diagnosis

* **Age-appropriate behavioral audiometry**

☐ Visual Reinforcement Audiometry ☐ Conditioned Play Audiometry
☐ Behavioral Observation Audiometry).

* **Acoustic immittance testing** – to evaluate middle ear function.

* **ENT (Otolaryngology) Consultant Consultation** – for further evaluation, counseling, and consideration of imaging studies (e.g., MRI/CT) to assess cochlear nerve integrity.

* **Phoniatric Consultation & Speech Therapy** – to support speech and language development.

* **Binaural Hearing Aid Fitting** – to support auditory access. & Consider assistive devices (e.g., FM system, remote microphone) to improve auditory access.

* **Consideration for Cochlear Implantation** – if limited or no benefit from hearing aids.

* **Regular Audiological Follow-Up** – to monitor hearing levels, hearing aid performance, and progress.

Note: Kindly refer to the attached ABR waveforms for more details.



(When ABR couldn't be done) Awake and restless child

Auditory brainstem response (ABR)

File NO:

Date:

Name: Sex: Age:

Reason for Referral: ☐ Failed newborn screening ☐ Speech delay ☐

Family history of hearing loss ☐ Follow-up ☐ Other: _____

Sedation: ☐ None – Natural Sleep ☐ General Anesthesia

Test Environment: ☐ Sound-treated booth ☐ Quiet hospital room
☐ Operating room

Stimulus Type & polarity: Rarefaction acoustic clicks were presented monaurally at rate of 27.5 p/sec., and intensity of 90 dBnHL down to threshold in 10-20 dB steps.

Equipment: Vivosonic Integrity™ ABR system

Transducer : Vivosonic Integrity™. Insert Earphones (ER-3C)

Electrode Montage: Non-inverting (Active): High forehead (Fz).

• Inverting: Mastoid / Earlobe. •

Ground: Low forehead.

Number of Sweeps: _____ (2000–4000)

Filter : 30–1500 Hz (infants)

Impedance Check: All electrodes $\leq 5 \text{ k}\Omega$. Inter-electrode difference $\leq 2 \text{ k}\Omega$

Result:

Test could not be reliably interpreted due to excessive movement and high EEG noise levels during recording (**awake and restless child**).

Diagnosis and conclusion:

ABR testing was **inconclusive** due to poor recording conditions.

No diagnostic information could be obtained.

Recommendations:

* **Reschedule ABR under optimal conditions** (preferably during natural sleep)

* **Age-appropriate behavioral audiometry** □ Visual Reinforcement Audiometry □ Conditioned Play Audiometry □ Behavioral Observation Audiometry).

* **Acoustic immittance testing** – to evaluate middle ear function.

* Consider ABR under **General Anesthesia (GA)** following **ENT and Anesthesia** Consultation.



Bone Conduction ABR

Used when **air conduction ABR cannot be performed** (atresia, middle ear disease).

Tests cochlear/neural function via **bone oscillator**.

- Use B-71 or B-81 bone vibrator.
- Often **no masking possible** in bilateral atresia.
- Estimates **better cochlea**, not ear-specific (unless masked).

Example Report

Result: Wave V traced down to 30 dBnHL via BC ABR.

Interpretation: Normal cochlear sensitivity ~1.5 kHz region.

Note: Ear-specific thresholds not confirmed due to lack of masking.

Tips & Pitfalls

Always state if masking was used.

Without masking = response reflects **better ear only**.

Useful for congenital atresia → supports BC hearing aid or CI planning.



Auditory Brainstem Response (ABR)**Neural Synchrony** (Clicks & CE-Chirp®)**BONE CONDUCTION****File NO:****Date:****Name:** **Sex:** **Age:****Reason for BC ABR:** ☐ Atresia, stenosis, or external ear malformation☐ Middle ear dysfunction☐ Other:**Sedation:** ☐ None – Natural Sleep☐ General Anesthesia**Test Environment:** ☐ Sound-treated booth ☐ Quiet hospital room ☐ Operating room**Stimulus Type & polarity:** Alternating (to reduce artifact) **acoustic clicks and (CE-Chirp®)** stimuli (to enhance neural synchrony across frequency regions) were presented monaurally at rate of 27.5 p/sec., and intensity of 50 dBnHL down to threshold in 10-20 dB steps.With **Masking** via Insert earphone (ER 3C) on **contralateral ear**.**Equipment:** Vivosonic Integrity™ ABR system**Transducer:** Vivosonic Integrity™. **Bone Oscillator:** B-71 or B-81**Electrode Montage:** Non-inverting (Active): High forehead (Fz).

• Inverting: Earlobe.

• Ground: Low forehead.

Number of Sweeps: (2000–4000)**Filter:** 30–1500 Hz (infants)**Impedance Check:** All electrodes $\leq 5 \text{ k}\Omega$.Inter-electrode difference $\leq 2 \text{ k}\Omega$ **Result:** **EAR identifiable and repeatable ABR** waves could be detected at 50 dBnHL,Wave (V) could be traced down to **30 dBnHL** in The EAR.**Diagnosis and conclusion:****ABR results indicate normal auditory neural Synchrony, Bone conduction thresholds are estimated to be within the 1–2 kHz frequency region, with peak contribution near 1.5 kHz.****Recommendations:*** **Age-appropriate behavioral audiometry** ☐ Visual Reinforcement Audiometry ☐ Conditioned Play Audiometry ☐ Behavioral Observation Audiometry).* **ENT (Otolaryngology) Consultation** – for further evaluation, counseling, and consideration of imaging studies (e.g., MRI/CT) and Bone conduction HA.* **Audiologic follow-up** is recommended, including **frequency-specific Tone Burst ABR with Narrow-Band CE-Chirp® stimuli**, for a more comprehensive evaluation of auditory function.

Auditory Brainstem Response (ABR)**Neural Synchrony** (Clicks & CE-Chirp®)**BONE CONDUCTION****File NO:****Date:****Name:** **Sex:** **Age:****Reason for BC ABR:** ☐ Atresia, stenosis, or external ear malformation☐ Middle ear dysfunction☐ Other:**Sedation:** ☐ None – Natural Sleep☐ General Anesthesia**Test Environment:** ☐ Sound-treated booth ☐ Quiet hospital room ☐ Operating room

Stimulus Type & polarity: *Alternating* (to reduce artifact) *acoustic clicks and (CE-Chirp®)* stimuli (to enhance neural synchrony across frequency regions) were presented monaurally at rate of 27.5 p/sec., and intensity of 50 dBnHL down to threshold in 10-20 dB steps.
 With **Masking** via Insert earphone (**ER 3C**) on **contralateral ear**.

Equipment: Vivosonic Integrity™ ABR system**Transducer:** Vivosonic Integrity™. **Bone Oscillator:** B-71 or B-81**Electrode Montage:** Non-inverting (Active): High forehead (Fz).

• Inverting: Earlobe.

• Ground: Low forehead.

Number of Sweeps: (2000–4000)**Filter:** 30–1500 Hz (infants)**Impedance Check:** All electrodes $\leq 5 \text{ k}\Omega$.Inter-electrode difference $\leq 2 \text{ k}\Omega$ **Result:** **EAR NO identifiable and repeatable ABR** waves could be detected at 50 dBnHL,

Wave (V) couldn't be traced at maximum bone conduction stimulation level **50 dBnHL** in
 The EAR.

Diagnosis and conclusion:

ABR results indicate **abnormal auditory neural Synchrony**, and Bone conduction thresholds are estimated to be **outside the normal range** within the 1–2 kHz frequency region, with peak contribution near 1.5 kHz.

Recommendations:

* **Age-appropriate behavioral audiometry** ☐ Visual Reinforcement Audiometry ☐ Conditioned Play Audiometry ☐ Behavioral Observation Audiometry).

* **ENT (Otolaryngology) Consultation** – for further evaluation, counseling, and consideration of imaging studies (e.g., MRI/CT).

* **Audiologic follow-up** is recommended, including **frequency-specific Tone Burst ABR with Narrow-Band CE-Chirp®** stimuli, for a more comprehensive evaluation of auditory function.

Auditory Brainstem Response (ABR)**Neural Synchrony** (Clicks & CE-Chirp®)**BONE CONDUCTION****File NO:****Date:****Name:** **Sex:** **Age:****Reason for BC ABR:** ☐ Atresia, stenosis, or external ear malformation☐ Middle ear dysfunction☐ Other: _____**Sedation:** ☐ None – Natural Sleep☐ General Anesthesia**Test Environment:** ☐ Sound-treated booth ☐ Quiet hospital room ☐ Operating room

Stimulus Type & polarity: *Alternating* (to reduce artifact) *acoustic clicks and (CE-Chirp®)* stimuli (to enhance neural synchrony across frequency regions) were presented monaurally at rate of 27.5 p/sec., and intensity of 50 dBnHL down to threshold in 10-20 dB steps.

Bone conduction ABR was recorded without contralateral masking due to bilateral atresia and absence of external ear access

Equipment: Vivosonic Integrity™ ABR system**Transducer:** Vivosonic Integrity™. **Bone Oscillator:** B-71 or B-81**Electrode Montage:** Non-inverting (Active): High forehead (Fz).

• Inverting: Earlobe.

• Ground: Low forehead.

Number of Sweeps: _____ (2000–4000)**Filter :** 30–1500 Hz (infants)**Impedance Check:** All electrodes $\leq 5 \text{ k}\Omega$.Inter-electrode difference $\leq 2 \text{ k}\Omega$ **Result:** identifiable and repeatable ABR waves could be detected at 50 dBnHL,

Wave (V) could be traced down to 30 dBnHL.

Diagnosis and conclusion:

ABR results indicate **normal auditory neural Synchrony**, Bone conduction thresholds are estimated to be within the **1–2 kHz frequency region**, with peak contribution near **1.5 kHz**.

NOTE: Responses reflect the **better hearing cochlea**, and ear-specific thresholds could not be **confirmed** due to absence of **contralateral masking**.

Recommendations:

* **Age-appropriate behavioral audiometry** ☐ Visual Reinforcement Audiometry ☐ Conditioned Play Audiometry ☐ Behavioral Observation Audiometry).

* **ENT (Otolaryngology) Consultation** – for further evaluation, counseling, and consideration of imaging studies (e.g., MRI/CT) and Bone conduction HA.

* **Audiologic follow-up** is recommended, including **frequency-specific Tone Burst ABR with Narrow-Band CE-Chirp®** stimuli, for a more comprehensive evaluation of auditory function.

Auditory Brainstem Response (ABR)
Neural Synchrony (Clicks & CE-Chirp®)
BONE CONDUCTION

File NO:

Date:

Name: Sex: Age:

Reason for BC ABR: ☐ Atresia, stenosis, or external ear malformation☐ Middle ear dysfunction☐ Other:**Sedation:** ☐ None – Natural Sleep☐ General Anesthesia**Test Environment:** ☐ Sound-treated booth ☐ Quiet hospital room ☐ Operating room

Stimulus Type & polarity: *Alternating* (to reduce artifact) *acoustic clicks and (CE-Chirp®)* stimuli (to enhance neural synchrony across frequency regions) were presented monaurally at rate of 27.5 p/sec., and intensity of 50 dBnHL down to threshold in 10-20 dB steps.

Bone conduction ABR was recorded without contralateral masking due to bilateral atresia and absence of external ear access

Equipment : Vivosonic Integrity™ ABR system**Transducer :** Vivosonic Integrity™. **Bone Oscillator:** B-71 or B-81**Electrode Montage:** **Non-inverting** (Active): High forehead (Fz).• **Inverting:** Earlobe.• **Ground:** Low forehead.**Number of Sweeps:** (2000–4000)**Filter :** 30–1500 Hz (infants)**Impedance Check:** All electrodes $\leq 5 \text{ k}\Omega$.Inter-electrode difference $\leq 2 \text{ k}\Omega$ **Result:** NO identifiable and repeatable ABR waves could be detected at 50 dBnHL,

Wave (V) couldn't be traced at maximum bone conduction stimulation level 50 dBnHL.

Diagnosis and conclusion:

ABR results indicate **Abnormal auditory neural Synchrony**, and Bone conduction thresholds are estimated to be **outside the normal range** within the **1–2 kHz frequency region**, with peak contribution near **1.5 kHz**.

NOTE: Ear-specific thresholds could not be confirmed due to absence of contralateral masking.

Recommendations:

* **Age-appropriate behavioral audiometry** ☐ Visual Reinforcement Audiometry ☐ Conditioned Play Audiometry ☐ Behavioral Observation Audiometry).

* **ENT (Otolaryngology) Consultation** – for further evaluation, counseling, and consideration of imaging studies (e.g., MRI/CT).

* **Audiologic follow-up** is recommended, including **frequency-specific Tone Burst ABR with Narrow-Band CE-Chirp® stimuli**, for a more comprehensive evaluation of auditory function.

Auditory Brainstem Response (ABR)
Neural Synchrony (Clicks & CE-Chirp®)
BONE CONDUCTION

File NO:

Date:

Name: Sex: Age:

Reason for BC ABR: ☐ Atresia, stenosis, or external ear malformation☐ Middle ear dysfunction☐ Other: _____**Sedation:** ☐ None – Natural Sleep☐ General Anesthesia**Test Environment:** ☐ Sound-treated booth ☐ Quiet hospital room ☐ Operating room

Stimulus Type & polarity: *Alternating (to reduce artifact) acoustic clicks and (CE-Chirp®) stimuli (to enhance neural synchrony across frequency regions) were presented monaurally at rate of 27.5 p/sec., and intensity of 50 dBnHL down to threshold in 10-20 dB steps. With Masking via Insert earphone (ER 3C) on contralateral ear.*

Equipment : Vivosonic Integrity™ ABR system**Transducer :** Vivosonic Integrity™. **Bone Oscillator:** B-71 or B-81**Electrode Montage:** Non-inverting (Active): High forehead (Fz).

• Inverting: Earlobe.

• Ground: Low forehead.

Number of Sweeps: _____ (2000–4000)**Filter :** 30–1500 Hz (infants)**Impedance Check:** All electrodes $\leq 5 \text{ k}\Omega$.Inter-electrode difference $\leq 2 \text{ k}\Omega$ **Result:**

Test could not be reliably interpreted due to excessive movement and high EEG noise levels during recording (awake and restless child).

Diagnosis and conclusion:

*ABR testing was **inconclusive** due to poor recording conditions.*

No diagnostic information could be obtained.

Recommendations:

* *Reschedule ABR under optimal conditions (preferably during natural sleep)*

* *Age-appropriate behavioral audiometry* ☐ Visual Reinforcement Audiometry ☐ Conditioned Play Audiometry ☐ Behavioral Observation Audiometry).

* *Acoustic immittance testing* – to evaluate middle ear function.

* *Consider ABR under **General Anesthesia (GA)** following **ENT** and **Anesthesia** Consultation.*

Auditory Steady State Response (ASSR)

ASSR is an **objective electrophysiological test** that estimates hearing thresholds across multiple frequencies simultaneously, using continuous modulated tones.

- Advantage: Provides **frequency-specific & ear-specific thresholds**.
- Often used when **ABR is absent** or inconclusive.
- Frequencies tested: 500, 1000, 2000, 4000 Hz.
- Results reported as **estimated thresholds (dB nHL → eHL)**.
- Can test **both ears & multiple frequencies** at once.
- Useful in **profound HL & CI candidacy assessment**.

Example Report

Result:

- RT: 500 Hz = 80 eHL, 1000 Hz = 85 eHL, 2000 Hz = 90 eHL, 4000 Hz = 95 eHL
- LT: 500 Hz = 80 eHL, 1000 Hz = 85 eHL, 2000 Hz = 90 eHL, 4000 Hz = 95 eHL

Interpretation: Bilateral severe-to-profound SNHL.

Recommendation: Candidate for cochlear implant evaluation.

Tips & Pitfalls

Use when ABR absent → gives thresholds where ABR cannot.

Always convert **nHL → eHL** using correction factors.

Time-consuming → needs patient cooperation or sedation.



ASSR (Auditory Steady-State Response) Report

File NO:

Date:

Name: **Sex:** **Age:**

Purpose of the Test

- Assess hearing thresholds in both ears.

Test Method

- ASSR measures brain responses to continuous modulated tones at specific frequencies.

- **Tested Ear:** Right / Left / Both

- **Frequencies Tested:** 500, 1000, 2000, 4000 Hz

- **Stimulus Delivery:** Insert earphones or headphones

- **Recording:** Scalp electrodes detect neural responses

Results and Interpretation

- ASSR provides an objective measurement of hearing thresholds for each frequency.

- Findings indicate:

- **Right ear:** -----

- **Left ear:** -----

*** Results Consistent with ABR.**

Kindly refer to the attached ABR report for more details.

Electrocochleography (ECochG)

ECochG records *electrical potentials from the cochlea and auditory nerve*.

It's mainly used to diagnose Meniere's disease / endolymphatic hydrops and sometimes auditory neuropathy.

- Measures:
 - **SP (Summating Potential)** = hair cell activity
 - **AP (Action Potential)** = auditory nerve firing
- The **SP/AP ratio > 0.4** is suggestive of Meniere's disease.
- Can be performed transtympanic (needle electrode) or extratympanic.

Example Report

Result:

SP amplitude: $0.45 \mu V$

AP amplitude: $0.8 \mu V$

SP/AP ratio = 0.56

Interpretation: Abnormally elevated SP/AP ratio → consistent with endolymphatic hydrops (Meniere's disease).

Recommendation: ENT follow-up, medical management for Meniere's.

Tips & Pitfalls

Always report **SP/AP ratio** clearly.

Transtympanic = more accurate, but invasive.

ECochG is supportive, not diagnostic alone → always combine with VNG, audiometry.



Electrocochleography (ECochG) Report***File NO:******Date:******Name:*** ***Sex:*** ***Age:******Electrode:*** ☐ *Transtympanic* ☐ *Extratympanic****Stimulus:*** *Clicks (80–95 dB nHL)****Filter:*** *10–1500 Hz****Results:******SP amplitude:*** ____ μV ***AP amplitude:*** ____ μV ***SP/AP ratio:*** ____***Interpretation:*** _____***Recommendations:*** _____

APPENDICES





Legal & Clinical Disclaimer



This book is intended solely as an educational, academic, and professional reference resource for audiology and audio-vestibular medicine.

The content presented herein is based on internationally recognized evidence-based principles, peer-reviewed literature, consensus statements, and widely accepted best-practice frameworks available at the time of writing. It is designed to support clinical reasoning, professional education, ethical awareness, documentation standards, and governance discussions.

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- *Legal advice or medico-legal opinion*
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- *Institutional policy, protocol, or clinical mandate*
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All clinical decisions, diagnostic interpretations, treatment plans, testing protocols, sedation practices, scopes of practice, privileges,

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- *Hospital credentialing and privileging committee approvals*
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Limitation of Interpretation

Audiological and electrophysiological test results, including auditory evoked responses, must always be interpreted within the full clinical context. These tests have inherent limitations and cannot independently establish diagnosis, prognosis, functional outcome, or quality of life.

Normal results do not guarantee absence of disease.

Abnormal results do not mandate specific interventions.

Uncertain results require cautious interpretation and appropriate follow-up.

Jurisdictional Notice

Standards of practice, scopes of authority, and professional roles vary between countries, institutions, and healthcare systems. Readers are responsible for ensuring compliance with the regulations and professional standards governing their own jurisdiction.



هذا الكتاب مرجع تعليمي ومهني مخصص لدعم ممارسة السمعيات وطب السمع والاتزان. يهدف إلى دعم التفكير الإكلينيكي وجودة التوثيق واتخاذ قرار أكثر أماناً اعتماداً على الدليل العلمي المنشور والممارسات المثلى والاتفاقيات الإرشادية المعتمدة عالمياً.

هذا الكتاب لا يُعد استشارة قانونية، ولا تعليمات تنظيمية ملزمة، ولا سياسة مؤسسية معتمدة، ولا بديلاً عن الأنظمة الوطنية أو اللوائح المحلية أو السياسات المعتمدة داخل أي منشأة صحية.

يجب أن تتوافق جميع الإجراءات والتفسيرات والقرارات الإكلينيكية مع الأنظمة واللوائح السارية ومتطلبات الترخيص المهني ولوائح المنشأة وإجراءات الاعتماد والامتيازات السريرية والسياسات المعتمدة.

كما أن نطاق الممارسة والامتيازات تختلف حسب الدولة والمنشأة والتصنيف الوظيفي.

أي ذكر لأجهزة، أو برامج أو شركات أو علامات تجارية أو منتجات تجارية هو لغرض الشرح التعليمي فقط. ولا يُعد بأي حال من الأحوال تركية أو توصية أو رعاية أو تفضيلاً أو ترويجاً لأي شركة أو منتج أو خدمة.

ويلتزم القارئ بتطبيق سياسات منشأته المتعلقة بتعارض المصالح والإفصاح.

أي نماذج أو قوالب أو أمثلة لسياسات واردة في هذا الكتاب هي للاسترشاد فقط، ولا يجوز تطبيقها دون مراجعة واعتماد رسمي من جهة الحوكمة المختصة داخل المنشأة.

المسؤولية النهائية عن رعاية المريض تقع على عاتق الممارس المرخص الذي يعمل ضمن نطاقه المعتمد وامتيازاته السريرية، وبما يتوافق مع إطار الحوكمة المؤسسية.

المؤلف

Dr Hany Abdou



APPENDIX A

MEET THE MANUFACTURERS

Evoked Response Systems in Clinical Practice



This final section serves as a practical bridge between the clinical theory discussed in previous chapters and the actual technology used in the field today. Here is an overview of what the "Meet the Manufacturers" chapter offers and how it fits into your study of auditory evoked responses.

1. Bridging Theory and Practice

*While earlier chapters focus on the physiological effects of drugs or the anatomy of the brainstem, this chapter focuses on the **hardware and software** required to capture those signals.*

*The chapter is organized **alphabetically** by manufacturer to provide an unbiased look at the current market. Each entry typically highlights:*

- **Equipment:** *Portable vs. desktop systems.*
- **Software Features:** *Automated detection algorithms, specialized filters, and normative data sets.*
- **Innovative Options:** *Advanced ways to process responses, such as Maximum Length Sequences (MLS) or specialized electrode arrays.*

2. Resources for the Clinician

The text emphasizes that this is more than just an equipment list; it is a learning tool. You can use this chapter to:

- ***Explore Hyperlinks:*** *Access direct research findings and technical white papers from the companies developing the technology.*
- ***Compare Stimuli & Electrodes:*** *See how different manufacturers implement the specific stimuli (like clicks or tone bursts) and electrodes (like tiptrodes or surface electrodes) discussed in earlier sections.*
- ***Stay Current:*** *Learn about modern systems capable of measuring responses from the "cochlea to the cortex."*

3. The Value of Industry Collaboration

*The author concludes with a note of gratitude, acknowledging that clinical progress in audiology is a partnership between **researchers, clinicians, and engineers.***

Key Takeaway: *Understanding the limitations and capabilities of your specific equipment is just as important as understanding the patient's physiology or drug history.*



Bio-logic® Hearing Systems/Natus® Hearing**www.natus.com**

As part of the "Meet the Manufacturers" initiative, **Natus Medical Incorporated** (and its **Bio-logic®** brand) provides a comprehensive look at the modern hardware used to perform the auditory assessments described in this book. Natus is a global leader in objective hearing assessment, particularly in newborn care and diagnostic neurology.

Below is a summary of the key systems and modules offered by Bio-logic/Natus.

1. Bio-logic Navigator® Pro (Diagnostic AEP)

The Navigator Pro is a versatile, PC-based platform designed for full-spectrum Auditory Evoked Potential (AEP) functionality.²

Key Capabilities:

- **Standard Testing:** Supports click and tone-burst ABR, ECochG, MLR, and ALR (including P300).
- **Advanced Features:** Mathematically calculates **waveform reproducibility** and uses **FSP (Fine Sampling Probability)** for statistical signal quality.
- **Ease of Use:** Features automatic electrode switching, meaning the clinician doesn't have to manually swap leads during a complex test battery.

- **GraphMaster:** A specialized tool that allows clinicians to compare a patient's latencies directly against age-referenced normative data.

2. Specialized Modules for Navigator Pro

Natus utilizes a modular software approach, allowing one hardware system to perform multiple specialized tests.

MASTER II (ASSR Module)

The **Multiple Auditory Steady-state Evoked Response (MASTER II)** is designed for rapid, objective frequency-specific threshold assessment.

- **Efficiency:** Can test up to **4 frequencies per ear simultaneously**.
- **Exponential Modulation:** A unique stimulus that enhances response amplitude at 500 Hz and 4000 Hz to get results closer to the true threshold.
- **High Intensity:** Capable of output up to 119 dB HL for assessing profound hearing loss.

Scout Diagnostic OAE

This module adds Distortion Product (DPOAE) and Transient Evoked (TEOAE) capabilities to the Navigator Pro, supporting frequencies up to 10,000 Hz.

3. Newborn Hearing Screening Systems

Natus offers several "gold-standard" automated systems specifically designed for the high-stakes environment of newborn hearing screening.

System	Primary Features	Technology
ABaer®	All-in-one workstation (ABR & OAE)	POVR Algorithm (Statistical ABR detection)
ALGO® 5	Cart-based, ergonomic workstation	AABR® (Automated ABR) - Screens both ears simultaneously
ALGO® 3i	Handheld, portable version of the ALGO	Infrared data transfer; "SpeedScreen" for fast data entry
Echo-Screen® III	Handheld, customizable modalities	Uses CHIRP or click stimuli; binomial statistical detection

The AABR® Advantage

The ALGO line is famous for its **Automated ABR (AABR)** technology. It uses a "gold-standard" statistical algorithm that provides a simple **Pass/Refer** result, requiring no waveform interpretation by the screener. This drastically reduces "refer" rates (false positives) compared to other methods.

4. Quality Management & Integration

A critical component of these systems is the **audble®** and **NERVE Center®** ecosystem:

- **Data Management:** Seamlessly exports reports to Electronic Medical Records (EMR).

- **Error Reduction:** The Echo-Screen III includes "Conflict Resolution" software to identify and correct data entry errors.⁸
- **Education:** The NERVE Center® provides clinical portals for ongoing audiologist and technician training.



GN OTOMETRICS**www.otometrics.com**

*In this section of "Meet the Manufacturers," the focus shifts to **Otometrics** (a GN Group brand), a global leader in hearing and balance diagnostics. With a legacy of "industry-firsts" dating back to the 1950s—including the first commercially available EP instrument—Otometrics provides a robust suite of tools for both diagnostic and screening applications.*

Below is an overview of their primary Auditory Evoked Response (AER) solutions.

1. ICS® Chartr EP 200 (Diagnostic System)

*The Chartr EP 200 is a comprehensive diagnostic platform designed for versatility and ease of use in clinical settings. It is a dual-channel system with a dedicated third channel for **Electromyography (EMG) monitoring**, which is critical for specialized tests like VEMP.*

Clinical Applications:

- **Standard Test Battery:** Includes ABR, ECochG, AMLR, and ALR.
- **Specialized Options:** Offers P300, ASSR, and both cervical and ocular VEMP (Vestibular Evoked Myogenic Potential).
- **ASSR Efficiency:** The optional ASSR module can test up to **12 frequencies simultaneously**, significantly reducing test time for frequency-specific threshold estimation.

Key Features for Interpretation:

- **Normative Data Integration:** The system includes published normative data (based on research from Boys Town National Research Hospital) and automatically generates **latency-intensity function graphs**.
- **Shared Database:** Integrates with VNG/ENG (balance testing) databases, allowing for a holistic view of the patient's otoneurologic status.
- **Remote Operation:** Supports off-the-shelf remotes, allowing clinicians to operate the system while staying close to infants or patients who require physical reassurance.

2. MADSEN® AccuScreen (Newborn Screening)

The AccuScreen is a lightweight, handheld device that facilitates the "two-step" screening process (OAE and ABR). It is built on data from over 36 million screenings worldwide.

Design for Workflow:

- **User Interface:** Features a large touch screen and a simple menu structure that reduces the number of clicks needed to start a test.
- **Angled Probe:** Specifically designed to provide a secure fit in the small ears of infants resting in car seats or bassinets.
- **Earphone Versatility:** The ABR screen can be performed using a traditional probe or disposable options like **Ear Hugs** or **Ear Couplers**.

3. Educational & Clinical Support

A standout feature of the Otometrics/Audiology Systems partnership is their emphasis on clinical education:

- ***Insights in Practice:*** *Highly regarded clinical publications that help audiologists bridge the gap between research and clinical application.*
- ***Advanced Training:*** *Offers regional classroom and online education with Continuing Education Units (CEUs).*
- ***Validation:*** *Both the Chartr EP and AccuScreen systems are backed by extensive peer-reviewed research, such as the validation of TEOAE-AABR technology for newborns.*

Summary Comparison: Natus vs. Otometrics

While both manufacturers offer high-tier technology, their "flavor" differs slightly:

- ***Natus/Bio-logic*** *is heavily integrated with the **ALGO** legacy and high-speed multi-frequency ASSR.*
- ***Otometrics/ICS*** *emphasizes the **integration of hearing and balance** (EP plus VNG/ENG) and user-centric designs like the angled AccuScreen probe.*



GSI**Grason Stadler****www.grason-stadler.com**

In this chapter, **Grason-Stadler (GSI)** showcases its legacy of user-friendly, high-quality audiometric instrumentation. Since 1949, GSI has been a staple in both clinical and research facilities. Their contributions to the "Meet the Manufacturers" section highlight a versatile range of diagnostic and screening tools, with a specific focus on maximizing neural responses through innovative stimuli.

1. GSI Audera: Comprehensive AEP and ASSR¹

The **GSI Audera** is a two-channel, computer-based system (laptop or desktop) that serves as a central hub for multiple auditory evoked potential tests.

- **Capabilities:** ABR, ECoChG, AMLR, ALR, ASSR, and DPOAE.
- **Data Management:** Uses an SQL database for efficient tracking of patient records.
- **Efficiency:** Features "one-click" module switching and custom test libraries, allowing clinicians to instantly load protocols specific to newborns, adults, or research subjects.

Innovation: The CE-Chirp® Stimulus

Perhaps the most significant clinical application mentioned is the use of the **CE-Chirp®** and **CE-Chirp Octave Bands**.

- **Mechanism:** Standard clicks often suffer from the "traveling wave" delay, where high frequencies reach their destination in the cochlea before low frequencies. The CE-Chirp compensates for this by timing frequencies so they reach the basilar membrane simultaneously.
- **Result:** This synchronization creates a much larger neural response. Wave V amplitudes can be **twice as large** as those produced by a standard click.
- **Benefit:** Robust waveforms lead to faster averaging times and easier identification of thresholds at low intensity levels.

2. Middle Ear and Audiometry Solutions

GSI is well-known for setting the "Gold Standard" in traditional audiometric and immittance testing.

- **TympStar Pro:** A touch-screen middle-ear analyzer.² It measures the mechanical acoustic properties of the ear, neural integrity (acoustic reflexes), and Eustachian tube function. It stores all immittance components (\$Y\$, \$B\$, and \$G\$) for comprehensive evaluation.
- **AudioStar Pro:** A clinical audiometer designed for speed.³ It features a "one-button, one-function" design and ergonomic light pipes to help clinicians stay focused on the patient rather than the dials.

3. Screening Tools: GSI Corti & Handhelds

For portable screening, GSI offers battery-operated solutions that utilize intelligent noise-rejection technology.⁴

- **GSI Corti:** A handheld OAE screener/diagnostic tool.⁵ It utilizes a **Patented Background Noise Algorithm** that can filter out "dirty" samples in real-time. This allows for accurate testing in environments with background noise as high as 55–65 dB, reducing the false referral rate in noisy hospitals.
- **GSI 39 & GSI 18:** Flexible screening products for tympanometry and basic air-conduction audiometry, ideal for mobile clinics or school screenings.

4. Summary of GSI's Unique Clinical Edge

Feature	Clinical Benefit
CE-Chirp Stimulus	Larger Wave V amplitudes; faster testing (fewer sweeps needed).
Adapting Noise Algorithm	Reliable OAE screening even in noisy environments (up to 65 dB).
One-Button Navigation	Reduces clinician fatigue and improves patient focus during long diagnostic sessions.



Intelligent Hearing Systems

www.ihsys.com



*In this final manufacturer profile, **Intelligent Hearing Systems (IHS)** presents its suite of advanced diagnostic and research-oriented tools. Founded by scientists and engineers, IHS is recognized for providing some of the most customizable and "power-user" features in the industry, particularly for advanced auditory research.*

1. SmartEP: The "Swiss Army Knife" of Evoked Potentials

SmartEP is a multi-channel system (up to 8 channels) that supports a massive range of tests, from basic screening to highly complex neurological research.

- ***Clinical Versatility:*** *Supports ABR, ECochG, MLR, LLR, and P300/MMN.*
- ***Research Capabilities:*** *Offers Frequency Following Responses (FFR), Complex ABR (cABR), and Somatosensory/Visual Evoked Potentials.*
- ***Innovative Interface:*** *Features a "Power Spectrum" display, allowing clinicians to see the frequency composition of the response itself. This helps identify whether noise or specific neural frequencies are dominating the recording.*

2. Advanced ECochG with Lilly TM-Electrodes

*IHS is a leader in Electrocochleography, particularly through their integration of the **Lilly TM-Wick Electrode**.*

- **Non-Invasive Placement:** This grounded electrode is placed directly against the tympanic membrane (eardrum). Because it is closer to the cochlea than a standard ear-canal electrode, it produces much larger and more repeatable waveforms.
- **Automated Analysis:** The software automatically calculates the **SP/AP Amplitude Ratio** and **Area Ratio**, which are critical for diagnosing conditions like Meniere's Disease.

3. Specialized Stimuli: iChirp and cABR

Like other leading manufacturers, IHS uses "Chirp" technology, but with a high degree of user customization.

- **iChirp:** Includes broadband and narrowband chirps to optimize Wave V identification. Uniquely, IHS provides a **Chirp Generation Module**, allowing researchers to build their own custom chirp stimuli.
- **cABR (Complex ABR):** Developed in collaboration with Dr. Nina Kraus's "Brainvolts" lab, this module is specifically for analyzing how the brain processes complex sounds like speech syllables ("BA", "DA", "GA"). It includes tools like **spectrograms** and **phaseograms** to visualize the brain's "tracking" of speech.

4. Efficiency and Quality Tools

IHS provides several "Smart" options to speed up clinical workflows without sacrificing data integrity:

- **Chained-Stimuli:** Instead of running one intensity at a time, this modality presents a "chain" of different volumes (up to

66/second), allowing an entire intensity-latency series to be captured much faster.

- **Eye-Blink Amplifier:** A dedicated hardware solution to monitor and reject "sweeps" (recordings) contaminated by eye-blink artifacts, ensuring the final average is clean.
- **Split Sweep Verification:** Data is recorded into two separate memory buffers simultaneously. This allows the clinician to objectively compare the two buffers to ensure the response is a true neural signal and not just random noise.

Summary of IHS Innovations

Tool/Feature	Primary Benefit
Lilly TM-Wick	Larger, more robust ECochG signals without surgery.
cABR Module	Advanced analysis of speech processing and brain plasticity.
8-Channel Input	Allows for complex brain mapping and multi-site monitoring.
Chained-Stimuli	Drastically reduces the time needed for threshold determination.



Interacoustics

www.Interacoustics.com



In this final manufacturer profile, **Interacoustics** highlights its **ECLIPSE** system, a platform that has become a global clinical standard through a strong partnership with leading researchers like Dr. Claus Elberling. Their focus is on high-precision threshold assessment and automated diagnostics.

1. Threshold Assessment with CE-Chirps®

Interacoustics has been at the forefront of the **CE-Chirp®** family of stimuli. Unlike traditional clicks, these are designed to provide optimum synchronization of the neural response across the cochlea.

- **Enhanced Amplitude:** CE-Chirps provide larger response amplitudes than standard clicks or tone bursts. This allows for **shorter averaging times** and more confident response detection, especially near the hearing threshold.
- **Narrow Band (NB) CE-Chirps:** These serve as a superior replacement for traditional Tone Bursts in frequency-specific testing.
- **Calibration Leadership:** They are one of the few manufacturers to use strictly published **peRETSPL** values, ensuring that the "0 dB" level is accurately standardized for these specialized stimuli.

2. Redefining ASSR

The ECLIPSE system aims to release the "full potential" of Auditory Steady-State Response (ASSR) by combining CE-Chirps with automated detection.

- **Speed and Efficiency:** Clinical studies show that a full 4-frequency, bilateral threshold assessment can be completed in approximately **20 minutes**.
- **Full Control:** Clinicians can present 8 stimuli (4 frequencies in each ear) simultaneously and adjust individual stimulation levels "on the fly" to save time.
- **eHL Conversion:** The software automatically applies age-specific and hearing-loss-specific correction factors to convert electrophysiological thresholds (nHL) into **Estimated Audiograms (eHL)**. This data can be exported directly to NOAH for immediate hearing aid fitting.

3. Advanced Diagnostic & Research Features

Beyond standard ABR, the ECLIPSE handles demanding clinical and research tasks with specialized processing:

- **Bayesian Weighting:** This is a sophisticated "weighted averaging" technique (similar to Kalman filtering). It helps reduce myogenic noise—such as when a child is restless but not sedated—by assigning less "weight" to noisy samples, resulting in a cleaner waveform faster than traditional rejection methods.
- **ECochG & eABR:** The system is designed with high-quality pre-amplifiers to capture the tiny signals required for

Electrocochleography and Electrical ABR (used in Cochlear Implant monitoring).

- **Research Module:** Allows researchers to import custom WAV files for stimuli and export raw data to **Excel or Matlab** for offline analysis.

4. Handheld Screening: The Titan

For neonatal screening, Interacoustics offers the **Titan**, a handheld device that complements the ECLIPSE.

- **ABRIS Option:** An automated infant hearing screening tool that uses both Clicks and CE-Chirps.
- **Multi-Modality:** Can be configured for ABR, TEOAE, and DPOAE screening or clinical diagnostics.

Summary of Clinical Guidelines from Interacoustics

Technical Factor	Clinical Impact
NB CE-Chirps	More accurate prediction of behavioral thresholds, especially at 0.5 kHz.
Bayesian Weighting	Enables successful testing of non-sedated children by filtering muscle noise.
Simultaneous ASSR	Provides a complete 8-point audiogram in roughly 22 minutes.
NOAH Integration	Safeguards the quality of pediatric hearing aid fittings by removing manual entry errors.



Maico**www.maico-diagnostics.com**

In this profile, **MAICO Diagnostics**—the company that coined the term "audiometer" in 1937—showcases its focus on ultra-fast, cost-effective newborn hearing screening. Their featured technology, the **MB 11**, reimagines how the Auditory Brainstem Response (ABR) is collected in clinical settings.

1. Innovation: The BERAphone®

The most distinct feature of MAICO's screening line is the **BERAphone®**. Unlike traditional systems that require disposable adhesive electrodes and ear tips, the BERAphone is an all-in-one integrated unit.

- **Integrated Hardware:** The preamplifier, acoustic transducer, and stainless-steel electrodes are all built into a single handheld unit.
- **Cost Efficiency:** By using water-soluble gel instead of disposable electrodes, the cost per screen is reduced to approximately **\$0.25**. This makes ABR screening affordable for hospitals that previously could only afford OAE (Otoacoustic Emission) screening.
- **Ease of Use:** The screener simply applies gel to the baby's skin and holds the BERAphone in place.³ There are no wires to tangle or adhesive pads to peel off.

2. Advanced Stimulation: The CE-Chirp®

Like several other top-tier manufacturers, MAICO utilizes the **CE-Chirp®** stimulus to overcome the limitations of the traditional "click."

- **Neural Synchrony:** A standard click reaches the high-frequency base of the cochlea before the low-frequency apex. The CE-Chirp "time-shifts" these frequencies so they reach their respective areas of the cochlea simultaneously.
- **Amplitude Boost:** This synchronization creates a response that is roughly **twice the amplitude** of a click-generated response, allowing the software to detect a "Pass" much faster.

3. Fast Steady State (FSS) Detection

The MB 11 uses a high repetition rate (93 Hz) to evoke a **Fast Steady State** response.⁶ This allows the system to analyze the data in the **frequency domain** rather than the time domain.

- **FFT (Fast Fourier Transformation):** The system converts the EEG signal into a spectrum. It looks for "harmonics" (multiples of the 93 Hz stimulus rate).
- **Objective PASS/REFER:** The software calculates a "test value" based on the amplitude and phase of eight harmonics. If this value crosses a critical threshold, the test terminates with a **PASS**.
- **Speed:** Because of this efficient detection, the median time to reach a result is only **28 seconds**.

4. Clinical Evidence and Research

Research conducted on the MB 11 BERAphone indicates high reliability in real-world hospital environments:

- **Sensitivity:** Studies on over 6,800 babies reported a **100% sensitivity** (no permanent hearing losses were missed).
- **Specificity:** The program achieved an overall specificity of **97.9%** after a two-stage screening process.
- **Electrical Noise Resistance:** Because the hardware can run on a laptop's battery, it is shielded from the electrical "noise" of hospital power lines, leading to cleaner recordings.

Summary of MAICO's Key Advantages

Feature	Clinical/Financial Benefit
BERAphone Design	Eliminates disposable costs; ideal for high-volume screening.
93 Hz Repetition Rate	Evokes a Fast Steady State response for rapid objective detection.
Binaural Testing⁷	The "Classic" model allows for simultaneous testing of both ears. ⁸
CE-Chirp Stimulus⁹	Larger wave amplitudes for faster thresholds and screening. ¹⁰



Vivosonic

Integrity™ V500



Vivosonic presents its **Integrity™ V500** and **Aurix™** systems.

Vivosonic's primary contribution to the field is a suite of technologies designed specifically to overcome the need for sedation by managing physiological and environmental noise.

1. The Challenge: Sedation and Artifacts

*Traditional ABR testing often requires infants to be sedated or in a deep natural sleep because muscle movement (**myogenic artifact**) and electrical interference can overwhelm the tiny neural signals.*

Vivosonic's mission is to provide "Quality ABR without Sedation," even when a baby is awake or in a noisy NICU.

2. Four Core Technologies

Vivosonic's "Integrity" system relies on a combination of four patented technologies to achieve clean recordings under non-ideal conditions:

I. VivoLink™ Wireless Technology

Unlike traditional tethered systems, the patient interface (VivoLink) communicates wirelessly with the computer.

- **Clinical Benefit:** *Caregivers can hold, stroll, or nurse an infant during the test.*

- **Noise Immunity:** Being battery-powered and untethered eliminates "line noise" from wall outlets and prevents cables from acting as antennas for electromagnetic interference.

II. The Patented Amplitrode®

The Amplitrode is the world's first **in-situ bio-amplifier**.

- **Mechanism:** It filters and amplifies the ABR signal directly at the electrode site before it travels down any cables.
- **Benefit:** By amplifying the signal "at the source," it prevents the environmental noise that usually leaks into long electrode wires from being amplified along with the brain's response.

III. SOAP™ Adaptive Processing

This is a noise-reducing algorithm based on **Kalman Weighted Averaging**.

- **Mechanism:** Instead of "rejecting" noisy sweeps (which wastes time), the system includes every sweep but assigns them a "weight." Clearer sweeps are weighted heavily, while noisy sweeps (from a baby moving or sucking) are given very low weight.
- **Benefit:** This allows the clinician to obtain a clear ABR waveform significantly faster, even if the patient is active.

IV. Time-Saving Statistical Tools

- **A & B Buffers:** The system concurrently displays two independent waveforms. Clinicians can see in real-time if the two traces correlate, confirming a true response without having to run a second, separate test.

- **Alternating-Split Polarity:** This allows for the real-time display of the **Cochlear Microphonic**, which is essential for diagnosing Auditory Neuropathy Spectrum Disorder (ANSD).

3. Clinical Evidence & Benefits

Independent research and clinical data (including studies by Dr. James W. Hall III) support the following outcomes:

- **Reduced Sedation:** Clinics report a **66% to 92% reduction** in the need for sedation.
- **Faster Diagnosis:** Wait times for ABR assessments dropped from months to just 1–3 weeks because patients no longer have to wait for an anesthesia slot.
- **Difficult-to-Test Populations:** Highly effective for children with **Cerebral Palsy**, **Down Syndrome**, or those suspected of **malinger**ing (faking hearing loss), as the system can distinguish true neural responses from intentional noise.

4. Product Range

- **Integrity™ V500:** The flagship diagnostic system supporting ABR, ECochG, DPOAE, TEOAE, ASSR, and VEMP.
- **Aurix™:** A fully automated ABR screening system designed for the NICU, using the same wireless and noise-reduction technologies to screen awake newborns.
- **VivoCheck™:** A unique tool that verifies the system's performance and measures the amount of electromagnetic interference in the room.

Summary of Vivosonic's Unique Impact

<i>Feature</i>	<i>Impact on Patient Care</i>
<i>Wake-state Testing</i>	<i>Reduces medical risks and parent anxiety associated with anesthesia.</i>
<i>Wireless Freedom</i>	<i>Permits testing in incubators (up to 30 feet away) or in a mother's arms.</i>
<i>Kalman Weighting</i>	<i>Extracts signals from muscle noise, preventing "No Response" results due to movement.</i>
<i>Telehealth Ready</i>	<i>Portability and noise immunity make it ideal for remote or rural clinics.</i>



APPENDIX B**ABBREVIATIONS**

ABR Auditory brainstem response

ASSR Auditory steady-state response

CAP Compound action potential

CM Cochlear microphonic

EEG Electroencephalography

EABR Electrical auditory brainstem response

ECAP Electrical compound action potential

ECochG Electrocochleography

EP Evoked potential

ERP Event-related potential

FFT Fast Fourier Transform

GBR Gamma-band response

LAEP Late auditory evoked potential

MLR Middle-latency response

MMN Mismatch negativity

SNR Signal-to-noise ratio

SN10 Slow negative wave at 10 ms

SP Sustained potential

SNR Signal-to-noise ratio



APPENDIX C

Drugs' Impact on Auditory Responses

1. Drug Categories and Their Effects

The impact of a drug on auditory testing depends largely on where that drug acts in the nervous system.

Drug Type	Effect on ABR	Effect on Cortical Responses
Psychotropic (Anti-depressants, sedatives)	Little to no influence	Significant modification
Anesthetics	Modest/Minimal effects	Varies (often significant)
Ototoxic (Antibiotics, Chemo)	Profoundly alters (due to cochlear damage)	Secondary alterations

2. Understanding Ototoxicity

Ototoxicity is ear damage resulting from therapeutic drugs. It primarily targets the **cochlea**, specifically the **hair cells** and the **stria vascularis**.

Key Risk Factors

Several factors increase the likelihood of drug-induced hearing loss:

- **Renal Function:** Since kidneys clear these drugs from the blood, impaired kidneys lead to higher drug toxicity.
- **Treatment Duration:** Courses longer than 10 days.
- **Synergy:** Taking "loop diuretics" (like Lasix) alongside ototoxic antibiotics.
- **Patient Profile:** Advanced age, pre-existing hearing loss, or specific genetic predispositions.

3. Clinical Monitoring and the Role of ABR

Because ototoxic drugs usually damage the **basal region** of the cochlea first, hearing loss starts at very high frequencies (above 8000 Hz).

Why use ABR for monitoring?

- **High-Frequency Sensitivity:** ABRs elicited with "clicks" or high-frequency tone bursts specifically stimulate the area of the cochlea most vulnerable to ototoxicity.
- **Patient Accessibility:** It is the primary tool for infants, surgical patients, or those in intensive care who cannot perform standard behavioral hearing tests.

Recommended Monitoring Schedule

1. **Baseline:** Before treatment or within the first 72 hours.
2. **During:** Weekly testing throughout the course of the drug.
3. **Follow-up:** Testing after the drug is discontinued (as damage can appear weeks or months later).

Note on Reversibility: While many drugs cause permanent damage, some (like aspirin, vancomycin, or chloroquine) may cause hearing loss that is potentially reversible once the medication stops.

how sedatives, hypnotics, and depressants impact auditory evoked responses, specifically the Auditory Brainstem Response (ABR).

1. The Continuum of CNS Depressants

These drugs act on the central nervous system (CNS) to reduce brain activity. They are categorized based on their intensity and duration of action.

- **Sedatives/Hypnotics:** Often called "conscious sedatives," they calm the patient or induce sleep, but the patient remains easily arousable.
- **Anesthesia:** The far end of the continuum, involving a deeper state of CNS depression (discussed as a separate category).

2. Impact on Auditory Responses

A recurring theme in the text is the differential effect of these drugs on different parts of the auditory pathway.

Drug Type	Effect on ABR (Brainstem)	Effect on Cortical Responses (ALR/ASSR)
Chloral Hydrate	No effect	Markedly affected
Diazepam (Valium)	Minimal / No effect	Definitely suppressed

<i>Drug Type</i>	<i>Effect on ABR (Brainstem)</i>	<i>Effect on Cortical Responses (ALR/ASSR)</i>
<i>Morphine</i>	<i>No effect</i>	<i>Minimal (acts on limbic system)</i>
<i>Meperidine</i>	<i>No effect</i>	<i>No apparent effect</i>
<i>Droperidol</i>	<i>No effect</i>	<i>Prolongs latency</i>

3. Specific Drug Profiles

Chloral Hydrate

- ***History:** Historically the most popular sedative for pediatric ABR.*
- ***Status:** Now falling out of use in the USA due to the long time required for sedation and recovery; replaced by faster agents like **Propofol**.*
- ***Dosage:** 50 mg/kg (max 1g).*
- ***Contra-indications:** Serious liver or renal disease.*

Benzodiazepines (e.g., Valium, Ativan)

- ***Clinical Use:** Often prescribed for adult patients with high anxiety to reduce muscle and movement artifacts that would otherwise ruin an ABR recording.*
- ***ABR Impact:** Minimal, making it a reliable choice for calming patients without distorting brainstem data.*

Narcotics & Opioids (e.g., Morphine, Meperidine)

- **Mechanism:** These drugs (specifically Morphine) target the **limbic system** (hippocampus and amygdala) rather than the primary sensory pathways.
- **ABR Impact:** Because they bypass the major sensory pathways involved in ABR generation, they do not influence the results, even in high doses used in ICUs.

4. Controlled Substance Schedules

The text notes that these drugs are "controlled," meaning they require a prescription and are categorized by the DEA (or similar bodies) based on their potential for abuse:

- **Schedule II:** High potential for abuse (e.g., Morphine, Ritalin, Pentobarbital). No refills allowed.
- **Schedule IV:** Lower potential for abuse (e.g., Valium, Librium, Chloral Hydrate).

how general anesthesia and specific anesthetic agents affect the Auditory Brainstem Response (ABR) and other auditory evoked potentials.

1. Defining General Anesthesia

General anesthesia is a drug-induced loss of sensation and consciousness. It is typically described in four stages:

1. **Analgesia:** No feeling of pain.
2. **Delirium:** Loss of voluntary control.
3. **Surgical Anesthesia:** Complete relaxation, regular breathing, and sluggish corneal reflex. **This is the target stage for surgery.**
4. **Medullary Depression:** Excessive anesthesia (danger zone).

Note: Hearing is the last of the senses to become nonfunctional during the induction of anesthesia.

2. ABR vs. Cortical Responses

The ABR is remarkably resilient compared to "extra-lemniscal" responses (like the AMLR and ALR). This is because the ABR is generated in the brainstem, while cortical responses involve complex, multi-synaptic pathways that are highly sensitive to suppression.

<i>Measurement Type</i>	<i>Resistance to Anesthesia</i>
<i>ABR (Brainstem)</i>	<i>High Resistance</i> (only modest latency shifts)
<i>AMLR / ALR (Cortex)</i>	<i>Low Resistance</i> (easily suppressed or abolished)

3. Specific Anesthetic Agents and ABR Impact

Popular Pediatric Agents

- **Propofol:** Highly popular due to quick recovery and low side effects. It causes **small, dose-dependent increases** in absolute latencies (Waves III and V) but does not adversely affect amplitude.
- **Sevoflurane:** Often used in the operating room. Studies show it can prolong Wave V latency by approximately 0.3 ms to 0.4 ms.

Volatile Inhalation Agents (Gases)

- **Nitrous Oxide:** Generally has no effect on ABR latency. However, it can inflate the middle ear, causing a **conductive hearing loss** that might artificially elevate ABR thresholds.

- **Halothane & Isoflurane:** Potent agents that cause slight, linear, dose-related delays in inter-wave latencies (roughly 0.2 ms).
- **Enflurane:** Can produce more significant inter-wave latency increases (up to 0.85 ms) at high concentrations.

Intravenous (IV) Agents

- **Ketamine:** A "dissociative" anesthetic that acts on the limbic system. It typically has **no effect** on ABR latency or amplitude.
- **Fentanyl:** A powerful synthetic opioid. At low doses, it has no apparent effect on ABR.
- **Barbiturates (Thiopental, Methohexital):** Results are mixed; while some show minimal effect, others report significant prolongation of Wave V latency (up to 0.7 ms).

4. Confounding Factors in the Operating Room

When interpreting ABR results under anesthesia, clinicians must account for physiological changes that are not caused by the drug itself:

- **Body Temperature:** Anesthesia can cause a drop in core temperature, which independently slows down ABR latencies.
- **Middle Ear Pressure:** As noted with Nitrous Oxide, gas accumulation can affect the conduction of sound.
- **Technical Settings:** Stimulus intensity, polarity, and filter settings must be consistent for accurate comparison.

how neuromuscular blockers, anticonvulsants, psychotropic agents, alcohol, and other miscellaneous drugs affect auditory responses.

1. Neuromuscular Blockers & Anticonvulsants

Neuromuscular Blockers (Paralyzing Agents)

Used in surgery and ICUs to cause muscle paralysis by blocking the skeletal neuromuscular junction.

- **Examples:** Curare, Succinylcholine, Pavulon.
- **Effect on ABR:** These drugs do not interfere with neural transmission in the auditory pathway. In fact, they often **improve ABR quality** because they eliminate myogenic (muscle) noise, resulting in a cleaner recording.

Anticonvulsants

Used to treat epilepsy (e.g., Dilantin).

- **Effect on ABR:** They typically cause a **prolongation of inter-wave latencies**, though amplitudes remain unchanged. These changes are often reversible.

2. Tranquilizers & Psychotherapeutic Agents

*These drugs are generally classified as **psychotropic**, meaning they affect mental state and brain function.*

- **Minor Tranquilizers:** (e.g., Valium) Anti-anxiety and sleep aids.
- **Major Tranquilizers:** Anti-psychotic agents used for serious mental health conditions.
- **Lithium:** Used for manic disorders.
- **Key ABR Finding:** While these drugs significantly impact **cortical responses** (the "higher" brain functions), they **do not affect the ABR**.

3. Alcohol: Acute, Chronic, and Withdrawal

Alcohol has a complex relationship with the auditory system, and its effects are often tied to physiological changes like body temperature.

Condition	Effect on ABR
Acute Ingestion	<i>Increased latencies (Waves III through VII); amplitudes unaffected.</i>
Chronic Abuse	<i>Prolonged inter-wave latencies (often correlated with brain atrophy).</i>
Withdrawal	Decreased latencies and increased amplitudes (reflecting CNS hyper-excitability).

Caution: *Alcohol intoxication often leads to **hypothermia** (lowered body temperature). Since cold temperatures naturally slow down ABR latencies, clinicians must distinguish between the effects of the alcohol itself and the effects of the cold.*

4. Miscellaneous Drugs

- **Nicotine:** *Can cause Wave I to have a longer latency and smaller amplitude in non-smokers, suggesting an effect at the very beginning of the auditory nerve.*
- **Lidocaine:** *While it can relieve tinnitus, high doses used for cardiac issues (arrhythmia) can prolong ABR inter-wave latencies.*
- **Mannitol:** *Used to reduce intracranial pressure. In brain-injured patients, it can actually **normalize** ABR latencies by relieving pressure on the brainstem.*

Summary

1. **Always consider the "Drug Factor":** Sedatives, anesthetics, and ototoxic drugs must be documented during any ABR analysis.
2. **Additive Effects:** Drug effects can combine with other factors (like body temperature or age) to skew results.
3. **ABR Resilience:** ABR is almost always more stable and less affected by drugs than cortical responses. No common medication completely suppresses the ABR.
4. **Statistical vs. Clinical Significance:** A drug might cause a "statistically significant" delay in a research study (e.g., 0.1 ms), but that shift might not be "clinically significant" enough to change a patient's diagnosis.



APPENDIX D

Test Protocols for Auditory Evoked Responses

Purpose of This Appendix

*This appendix provides **general framework protocols** for evoked response testing. Protocols should be adapted to:*

- *Patient age*
- *Clinical question*
- *Institutional policies*
- *Equipment capabilities*

These protocols support consistency but do not replace clinical judgment.

General ABR Diagnostic Protocol

- *High intensity click stimulation*
- *Replication at each condition*
- *Analysis of absolute and interpeak latencies*
- *Interaural comparison*

Used for assessment of neural integrity.

ABR Threshold Estimation Protocol

- *Frequency specific tone bursts*
- *Stepwise intensity reduction*
- *Replication near threshold*
- *Application of correction factors*

Used primarily in pediatric assessment.

Pediatric ABR Protocol

- *Natural sleep whenever possible*
- *Age appropriate norms*
- *Conservative interpretation*
- *Integration with OAE and immittance testing*

ECochG Protocol

- *Polarity manipulation*
- *Proximity optimized electrode placement*
- *Identification of cochlear microphonic and neural components*
- *Pattern based interpretation*

Clinical Pearl

*Protocols guide testing, but **data quality and replication** define validity.*



APPENDIX E

HOSPITAL POLICY

Auditory Brainstem Response (ABR) Under Sedation / General Anesthesia

1. PURPOSE

*This policy establishes standardized, safe, and medico-legally defensible procedures for performing **Auditory Brainstem Response (ABR)** testing under **sedation or general anesthesia (GA)**.*

The objective is to:

- ☐ *ensure patient safety*
- ☐ *standardize clinical interpretation*
- ☐ *prevent false reassurance*
- ☐ *define medico-legal documentation standards*
- ☐ *clarify professional responsibilities*

2. SCOPE

This policy applies to:

- ☐ *Audiology departments*
- ☐ *Otolaryngology services*
- ☐ *Anesthesia teams*
- ☐ *Pediatric services*
- ☐ *Cochlear Implant programs*

It covers:

- ☐ *infants, children, and medically complex patients*
- ☐ *diagnostic ABR performed under sedation or GA*

3. INDICATIONS FOR ABR UNDER SEDATION / GA

ABR under sedation or GA **may be considered** only when:

- ☐ reliable testing cannot be obtained in natural sleep
- ☐ behavioral audiometry is not feasible
- ☐ results are required to guide clinical decisions
- ☐ patient safety is ensured by anesthesia team

ABR under GA is NOT a routine test.

4. NON-INDICATIONS (WHEN NOT TO USE SEDATED ABR)

Sedated ABR **must NOT** be used to:

- ☐ assess speech understanding
- ☐ predict language outcomes
- ☐ guarantee cochlear implant outcomes
- ☐ replace cortical auditory assessments

5. ROLES & RESPONSIBILITIES

5.1 Audiologist

- ☐ performs and interprets ABR
- ☐ understands physiologic effects of sedation
- ☐ documents limitations
- ☐ avoids absolute conclusions

5.2 Anesthesiology Team

- ☐ determines sedation / GA eligibility
- ☐ monitors physiologic stability
- ☐ documents drugs and depth of anesthesia

5.3 ENT / Otology

- ☐ Consultant of record in OR.

- ☐ *integrates results into overall clinical decision*

6. PRE-PROCEDURE REQUIREMENTS

Before sedated ABR:

- ☐ *documented indication for sedation*
- ☐ *informed consent (including limitations of sedated ABR)*
- ☐ *anesthesia clearance*
- ☐ *baseline otologic assessment*

7. Interpretation Standards

- ☐ *sedated/GA conditions must be stated*
- ☐ *awake normative data **must not** be applied*
- ☐ *latency shifts expected and documented*

8. MANDATORY DOCUMENTATION REQUIREMENTS

*Every ABR under sedation / GA report **MUST INCLUDE:***

- ☐ *Type of sedation or GA*
- ☐ *Follow-up recommendation*

“Auditory Brainstem Responses were recorded under sedation/general anesthesia, which may influence waveform morphology and timing.”

“Findings obtained under sedation do not independently assess functional hearing, cortical auditory processing, or language development.”

“Continued audiologic and developmental follow-up is recommended.”

SCOPE OF PRIVILEGES

Privileges may be granted for one or more of the following levels:

Level I — Basic Evoked Responses

- ☐ *ABR (natural sleep / awake)*
- ☐ *ASSR*
- ☐ *ECochG (non-invasive)*
- ☐ *Cortical auditory evoked potentials (CAEPs)*

Level II — Advanced Evoked Responses

- ☐ *Frequency-specific ABR*
- ☐ *Bone-conduction ABR*
- ☐ *Aided ABR / ASSR*
- ☐ *eABR (CI-related)*

Level III — High-Risk Evoked Responses

- ☐ *ABR under **sedation or GA***
- ☐ *Intra-operative monitoring (where applicable)*
- ☐ *CI candidacy–related electrophysiology*

Sleep Deprivation Recommendation

For Performing ABR Under Natural Sleep

A Safer First-Line Strategy Before Sedation

Why Natural Sleep Is Always Preferred

*Whenever possible, **ABR** should be performed during natural **sleep** before considering sedation or general anesthesia.*

Natural sleep:

- ☐ *preserves normal auditory physiology*
- ☐ *avoids drug-related latency shifts*

- ☐ *reduces medico-legal risk*
- ☐ *provides results that are easier to interpret*

Sedation is an alternative—not the default.

Indications for Sleep-Deprived ABR

Sleep-deprived ABR is recommended when:

- ☐ *the child is medically stable*
- ☐ *the child can reasonably achieve natural sleep*
- ☐ *there is no urgent indication requiring GA*
- ☐ *parents can comply with preparation instructions*

Especially recommended for infants and young toddlers.

Sleep Deprivation Protocol (Parent Instructions)

The Night Before the Test

Parents are instructed to:

- ☐ *reduce the child's sleep by **4–6 hours** (age-dependent)*
- ☐ *avoid long naps*
- ☐ *wake the child earlier than usual*

Total sleep deprivation is NOT required and NOT recommended.

On the Day of the Test

- ☐ *Keep the child awake until arrival*
- ☐ *Feed the child immediately before the test (breastfeeding or bottle)*
- ☐ *Ensure the child is comfortable and warm*

A fed, tired baby sleeps better than a sedated one.

Natural sleep does not distort ABR physiology.

Clinical Advantages Over Sedation

When Sleep Deprivation Fails

Sleep-deprived ABR may be unsuccessful if:

- ☐ *child cannot maintain sleep*
- ☐ *excessive movement persists*
- ☐ *medical condition prevents safe deprivation*

In such cases:

sedation / GA may be considered

with full policy, privilege, and consent compliance

Mandatory Documentation (Best Practice)

Every report should state:

“ABR was attempted under natural sleep following sleep-deprivation preparation.”

If unsuccessful:

“Adequate natural sleep could not be achieved despite preparation; sedated ABR may be considered if clinically indicated.”

Common Mistakes to Avoid

skipping natural sleep attempt

over-depriving the child

jumping to GA without documentation

Clinical Decision Rule

If ABR can be done safely during natural sleep, sedation is not justified.

Clinical Summary

- ☐ *Natural sleep ABR is first-line*
- ☐ *Sleep deprivation improves success without physiologic distortion*

— *Sentence That Protects Practice*

“Natural sleep ABR following sleep-deprivation preparation is the preferred initial approach and should be attempted before considering sedation or general anesthesia.”

The safest ABR is the one that lets the brain behave normally.

*Sleep Deprivation Recommendation for ABR Under Natural Sleep
Clinical Safety, Seizure Risk, and When NOT to Deprive Sleep
A Patient-Safety–First Chapter*

*Sleep deprivation is a **tool**, not a rule.*

And like any tool in medicine,

it must never override patient safety.

Sleep deprivation is not mandatory for ABR—and is not safe for every child.

*Sleep deprivation is commonly used to facilitate **natural sleep ABR**, but it is **not benign** in all children.*

Certain populations—especially those with neurological vulnerability—

*may be at **real risk** if sleep deprivation is applied indiscriminately.*

This is not theoretical.

This is real-world practice.

Core Safety Principle (Non-Negotiable)

No diagnostic test justifies provoking a medical emergency.

— *The Seizure Concern (Very Real)*

*Sleep deprivation is a **known seizure trigger** in:*

- ☐ *children with epilepsy*

- ☐ children with suspected seizures
- ☐ children with abnormal EEG history
- ☐ some neurologically vulnerable infants

A parent expressing fear of seizures is a **clinical red flag**, not anxiety.

If a Parent Says: “My child may convulse if he stays awake”

That statement **must be taken seriously**.

— **Absolute Contraindications to Sleep Deprivation**

Sleep deprivation **must NOT be recommended** in children with:

Known epilepsy

Suspected seizure disorder

Prior febrile or afebrile seizures (unless cleared)

Abnormal EEG (known)

Significant hypoxic brain injury

Parental report of seizure risk

Parental report alone is sufficient to stop deprivation.

No test overrides this.

— **Safe Alternatives to Sleep Deprivation**

When sleep deprivation is unsafe:

Option 1 — Natural Sleep Without Deprivation

- ☐ test scheduled around usual nap
- ☐ feeding immediately before test
- ☐ warm, quiet environment

Option 2 — Partial / Minimal Adjustment

- ☐ mild schedule adjustment only
- ☐ **never more than clinically safe**

Option 3 — Sedated ABR

- ☐ only if clinically justified
- ☐ with full policy, privilege, and consent
- ☐ after documenting why natural sleep was unsafe

Part VI — Mandatory Documentation

If sleep deprivation is **NOT** used due to seizure risk, document:

“Sleep deprivation was not recommended due to concern for seizure risk based on parental history and neurological vulnerability.”

If neurology was consulted:

“Neurology consultation was obtained prior to proceeding with testing strategy.”

This sentence alone can save you legally.

— What Must NEVER Be Said

“Sleep deprivation is harmless”

“It’s routine”

“Nothing will happen”

“We have to do it”

*These statements are **indefensible**.*

Key Points

- ☐ Sleep deprivation is optional, not mandatory
- ☐ Parental concern is a valid contraindication
- ☐ Neurology referral is appropriate and protective

Common Mistakes

- ☐ treating deprivation as routine
- ☐ ignoring parental warnings

Red Flags

- ☐ *parent mentions seizures*
- ☐ *abnormal neurologic history*

Take-Home Messages

- ☐ *Safety first*
- ☐ *Listen to parents*

— The Sentence That Protects You Completely

***The safest ABR is not the one done fastest—
but the one done without harm.***

Parent-Safety Sentence

Neurology Clearance Form

Neurology Clearance for ABR Preparation

Patient Name: _____

MRN: _____

Date of Birth: _____

Reason for Consultation

- ☐ *Planned ABR under natural sleep*
- ☐ *Consideration of sleep deprivation*
- ☐ *History or concern of seizures*

Neurological History

- ☐ *No known seizure history*
- ☐ *Febrile seizures*
- ☐ *Non-febrile seizures*

- ☐ Suspected seizure disorder
- ☐ Abnormal EEG
- ☐ Neurologic developmental delay
- ☐ NICU brain injury
- ☐ Other: _____

Neurology Assessment

Based on clinical evaluation:

- ☐ Sleep deprivation is **SAFE**
- ☐ Sleep deprivation is **NOT RECOMMENDED**
- ☐ Natural sleep without deprivation only
- ☐ Sedated ABR preferred if testing required

Neurologist Statement

I confirm that I have reviewed the patient's neurological status and provided guidance regarding the safety of sleep deprivation in preparation for ABR testing.

Neurologist Name: _____

Signature: _____

Date: _____



Protocols



Suggested Tone Burst ABR Test Parameters:

*This table outlines the essential parameters for conducting a **Tone Burst ABR**, which is the gold standard for estimating frequency-specific hearing thresholds in infants and children who cannot provide behavioral responses.*

Unlike the standard click ABR, which provides a broad estimate of high-frequency hearing, tone bursts allow clinicians to "build an audiogram" by testing specific frequencies like 500 Hz, 1000 Hz, 2000 Hz, and 4000 Hz.

1. Stimulus Parameters

- **Type:** *Tone bursts are used because they have a more concentrated frequency spectrum than clicks.*
- **Polarity: Condensation** *is standard for air conduction (AC). For bone conduction (BC), **alternating** polarity is vital to cancel out the stimulus artifact that often obscures Wave V.*
- **Rate:** *Typically set to **27.7/sec**. A faster rate (**39.1/sec**) is often used for 500 Hz to speed up testing, as lower frequencies require more time to resolve.*

2. Recording Settings

- **Time Window (Epoch):** *Because tone burst responses (especially at 500 Hz) have longer latencies than clicks, a longer*

window of **20–30 ms** is required. Using a standard 10 ms window would likely cut off the response.

- **Filter Band:** A lower high-pass filter (**30 Hz**) is often preferred for tone bursts to capture the low-frequency energy of the response, particularly for Wave V and the following slow negative trough (SN10).
- **Sweeps:** Because the response amplitude is smaller than a click ABR, more averaging is needed. Near the hearing threshold, you may need well over **2,000 sweeps** to distinguish the signal from the noise.

3. Patient Factors & Setup

- **Electrode Montage:** A two-channel setup is ideal. The second channel (inverting at the nape) can help clarify Wave V when the primary earlobe/mastoid channel is noisy.
- **Subject State:** The patient **must** be still. Myogenic (muscle) noise from a moving or crying child will completely drown out the tiny neural signal of a tone burst ABR.

Summary of Rationale

Feature	Clinical Rationale
Why Tone Bursts?	To determine the "shape" of the hearing loss (e.g., sloping vs. flat).
Why 20-30 ms window?	Lower frequencies take longer to travel through the cochlea, resulting in later peaks.

<i>Feature</i>	<i>Clinical Rationale</i>
<i>Why 30 Hz High Pass?</i>	<i>To preserve the robust, rounded Wave V common in low-frequency tone burst responses.</i>

cross-check" approach to pediatric hearing assessment

This suggested protocol follows a comprehensive "cross-check" approach to pediatric hearing assessment. By combining electrophysiological, acoustic, and physiological measures, clinicians can accurately differentiate between conductive, sensory, and neural types of hearing loss.

1. Otoacoustic Emissions (OAE)

Purpose: *To assess the health of the outer hair cells in the cochlea.*

- ***Identification of ANSD:*** *If OAEs are present but the ABR is absent or abnormal, the patient may have **Auditory Neuropathy Spectrum Disorder (ANSD)**.*
- ***DPOAE Criteria:*** *Testing specifically at 2, 3, and 4 kHz helps confirm high-frequency cochlear integrity. A passing response requires the emission to be above 0 dB SPL and have a signal-to-noise ratio (SNR) of at least 6 dB.*

2. Middle-Ear Measures

Purpose: *To rule out or confirm the presence of middle-ear fluid (otitis media) or ossicular issues that could explain a hearing loss.*

- ***High-Frequency Tympanometry:*** *For infants under 7 months, a **1000 Hz probe tone** is required. Standard 226 Hz tones are inaccurate in infants because their ear canals are highly*

compliant and can produce a "normal" looking graph even in the presence of fluid.

- **Middle-Ear Muscle Reflex (MEMR):** Absence of reflexes at 1 and 2 kHz, despite normal tympanometry, is another strong indicator of neural dysfunction (ANSD) or a significant hearing loss.

3. Preliminary Click ABR

Purpose: To quickly check general neural synchrony and determine the starting point for threshold testing.

- **Polarity Check:** Running both **condensation and rarefaction** clicks is essential. If the resulting waveforms "flip" (invert) when polarity changes, the clinician is seeing a **Cochlear Microphonic**, not a true neural ABR. This is a hallmark of ANSD.
- **Tube Clamping:** If a large response is seen but hearing loss is suspected, clamping the insert earphone tube stops the sound. If the response remains on the screen, it is **electrical artifact** (leakage); if it disappears, it was a biological response.

4. Tone Burst ABR (Threshold Prediction)

Purpose: To estimate the specific hearing levels across the frequency range (building the "eHL" audiogram).

- **Test Order:** Start with **2000 Hz** (most critical for speech) and **500 Hz** (to rule out a "rising" or "sloping" loss).

- **Search Strategy:** Use a "bracket" method. Start at 75 dB nHL, drop by 20 dB if a response is present, and then refine by 10 dB to find the lowest level where **Wave V** is still visible.
- **Bone Conduction (BC):** If air conduction thresholds are abnormal, BC is performed using **alternating polarity**. This identifies if the loss is **conductive** (normal BC) or **sensorineural** (abnormal BC).

Summary Table for Final Diagnosis

Finding	Diagnosis
Normal OAE, Absent ABR, Absent Reflexes	Auditory Neuropathy (ANSD)
Flat Tympanogram, Abnormal AC, Normal BC	Conductive Hearing Loss (e.g., fluid)
Absent OAE, Abnormal AC, Abnormal BC	Sensorineural Hearing Loss



Glossary



This glossary provides definitions for key terms used in the clinical application of Auditory Brainstem Response (ABR) and other auditory evoked potentials.

Core Electrophysiological Terms

- **Auditory Brainstem Response (ABR):** *An auditory evoked potential representing neural activity from the eighth cranial nerve and brainstem pathways. Also called **BAER** or **BAEP**.*
- **Absolute Latency:** *The time (in milliseconds) from the start of a stimulus to a specific peak in the resulting waveform.*
- **Amplitude:** *The magnitude or "size" of a neural response, typically measured in microvolts (μV) for ABR.*
- **Signal Averaging:** *A computer technique that sums successive samples of brain activity time-locked to a stimulus. This reduces background "noise" and improves the signal-to-noise ratio.*
- **Common Mode Rejection (CMR):** *A noise-reduction strategy where a differential amplifier subtracts electrical signals (noise) that are identical at two different electrodes.*

Anatomy and Physiology

- **Brainstem:** *The portion of the brain containing the medulla, pons, and midbrain; it connects the spinal cord to the higher brain centers.*

- **Cochlear Microphonic (CM):** *An alternating-current potential from the cochlear hair cells that mimics the waveform of the incoming sound signal.*
- **Cortex:** *The outer layers of gray matter in the cerebral hemispheres responsible for high-level processing.*
- **VIIIth Nerve:** *The vestibulocochlear nerve, which carries both balance (vestibular) and hearing (cochlear) information to the brain.*

Clinical Measurements and Diagnostics

- **Electrocochleography (ECochG):** *A method of recording potentials (CM, SP, and AP) directly from the cochlea and eighth nerve using electrodes in the ear canal or on the promontory.*
- **Hearing Threshold Level (HTL):** *An individual's hearing threshold relative to the average threshold of normal-hearing young adults.*
- **Immittance:** *A battery of tests (including tympanometry) that measures how easily energy flows through the middle ear system.*
- **Intraoperative Monitoring:** *The continuous assessment of neural integrity (usually via ABR or ECochG) during a surgical procedure to prevent nerve damage.*
- **Otoacoustic Emissions (OAEs):** *Very low-level sounds produced by a healthy cochlea, which can be measured in the ear canal to screen for outer hair cell function.*

Stimulus Parameters

- ***Click:*** A very brief (rapid onset), broad-band sound used to trigger a synchronous neural response across a wide range of frequencies.
- ***Toneburst:*** A sound signal with a defined rise, plateau, and fall time, allowing it to be perceived as having a specific pitch or tonal quality.
- ***Transducer:*** Any device that converts one form of energy into another, such as an earphone (electrical to acoustic) or a bone oscillator (electrical to mechanical vibration).
- ***Rise Time:*** The time it takes for a sound signal to go from silence to its maximum intensity.

Pathology and Imaging

- ***Acoustic Neuroma (Schwannoma):*** A benign tumor growing on the sheath of the VIIIth nerve.
- ***Demyelinating Disease:*** A condition, such as ***Multiple Sclerosis***, where the protective myelin coating of nerve fibers is damaged, slowing neural conduction.
- ***Magnetic Resonance Imaging (MRI):*** A radiological tool that uses magnetic fields and radio waves to create detailed images of internal anatomy, often used to confirm ABR findings of a tumor.



References



This comprehensive reference list details the foundational and evolving scientific research across the field of audiology, including diagnostics, pediatric care, and advanced rehabilitation.

Clinical Standards and Professional Guidelines

- ***ASHA Guidelines:*** *Standards for audiometric symbols (1990), pure-tone audiometry (2005), and audiological screening (1997) are established by the **American Speech-Language-Hearing Association**.*
- ***ANSI Standards:*** *The **American National Standards Institute** specifies requirements for audiometer specifications (2004, 2010), ambient noise levels (1999), and acoustic immittance instruments (1987).*

E. references

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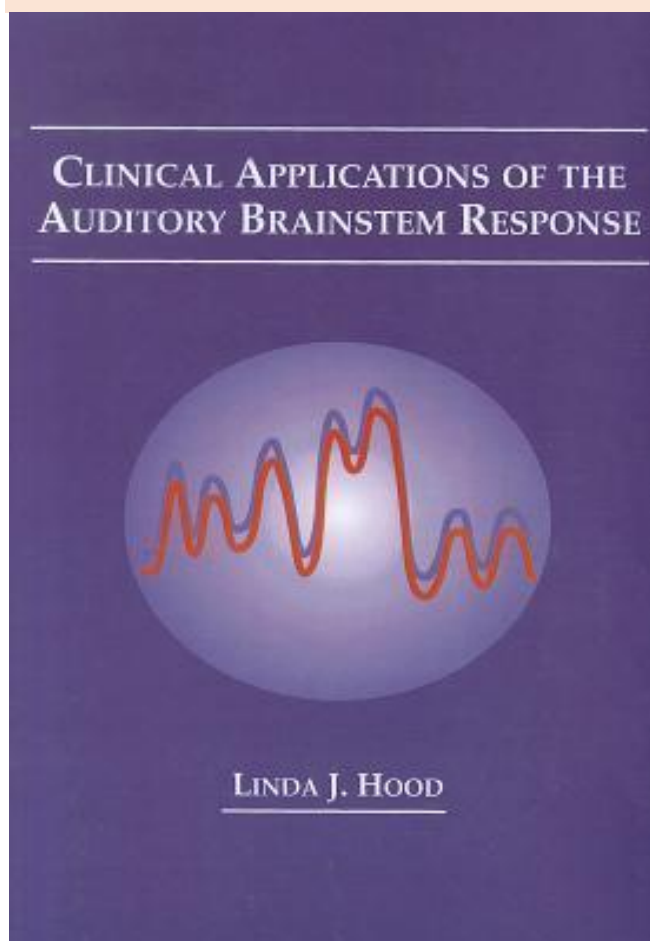
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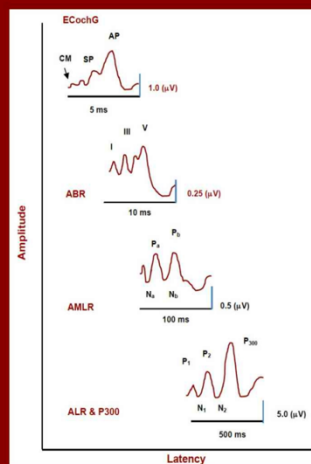


Textbooks

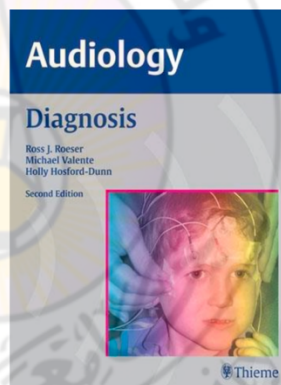
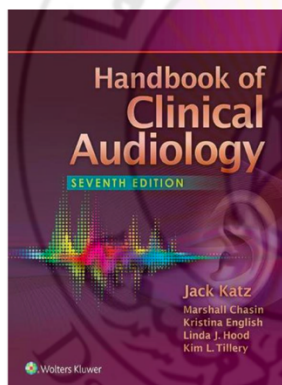
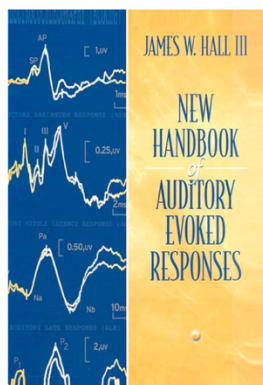


eHandbook of Auditory Evoked Responses

Principles, Procedures & Protocols



James W. Hall III





FINAL CLOSING MESSAGE



The Moment After the Last Wave

You will close this book with more knowledge.

But knowledge alone was never the goal.

You will recognize waveforms faster.

You will adjust parameters with confidence.

*You will know when a response is **present, absent, delayed, or distorted.***

*But the real skill begins **after** the recording ends.*

*When the screen is **quiet.***

*When the printer **stops.***

*When the numbers look **perfect.***

And the patient is still in front of you.

*Evoked responses were never meant to replace thinking.
They were never designed to make decisions for us.
They exist to **support** judgment, not to absolve it.
A **clean waveform** does not equal a **clean answer**.
A **normal result** does not guarantee a **normal life**.
And an **abnormal** trace does not always explain
suffering.*

*What defines you is not how well you record,
but how wisely you **interpret**.
Not how confidently you report,
but how honestly you communicate uncertainty.
Not how fast you finish a test,
but how carefully you decide **when not to test at all**.*

***This book was written to stand in the space
where machines stop and responsibility begins.***

*Where evidence meets ethics.
Where objectivity meets humility.
Where clinical skill is measured not by certainty,
but by restraint.*

*If this book has done its job,
you will look at evoked responses differently.*

*Not as answers,
but as questions that demand context.
Not as proof,
but as signals that require wisdom.
And not as protection from error,
but as a reminder of the weight we carry
each time we sign a report.*

The last wave has been recorded.

The real work now belongs to you.

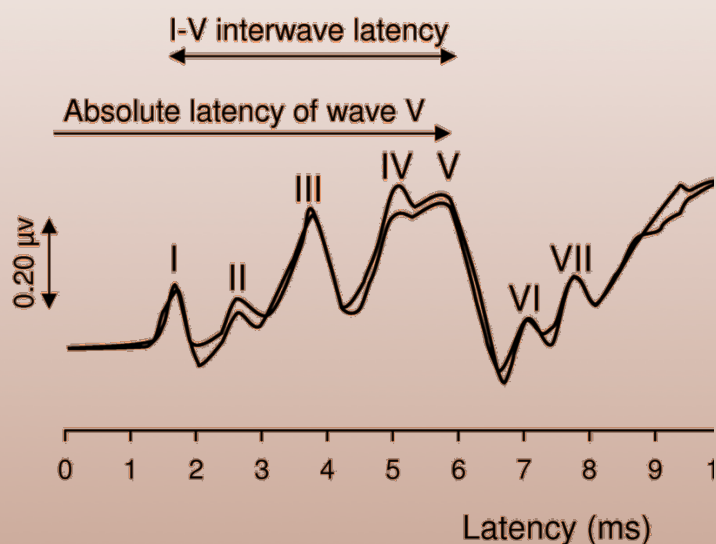
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Auditory Evoked Potentials in Clinical Decision-Making Evidence, Ethics, and Real-World Practice



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**Auditory Evoked
Potentials in Clinical
Decision-Making**

**Hany
Abdou**

**Dr/Hany Abdou
M.Sc. Audio-
Vestibular Medicine**

Auditory Evoked Potentials in Clinical Decision-Making

Dr. Hany Abdou has spent years working in busy clinical environments. where audiology decisions are made under real pressure

